THE

GEOLOGICAL MAGAZINE

VOLUME LXVII.

No. VIII.—AUGUST, 1930.

ORIGINAL ARTICLES.

The Generic Position and Phylogeny of Some Jurassic Arcidae.

By W. J. Arkell, M.A., D.Phil., B.Sc.

(Concluded from p. 310.)

VI. Jurassic Species of Parallelodon and Sub-Genera.

So much confusion has occurred in the past over the identification of the genera which we have been discussing, that a list of some figured species from the Jurassic rocks, arranged in their proper sub-genera, may be useful. The only previous attempt at a list of this sort, so far as I am aware, is that by Professor Rollier, who was only able to enumerate five species.[1] He called all these *Beushausenia*, but two are not Beushausenias but true Parallelodons, while a third belongs to a different genus.

Genus Parallelodon Meek and Worthen, 1866, *sensu stricto* = *Macrodon* Buckman. 1845, non Müller 1842.

Type: *P. rugosum* (Buckman); alate.

Kimeridgian Species.

P. mosensis (Buvignier) (sub *Arca*), Stat. géol. dépt. de la Meuse, Atlas, p. 20, pl. xvi, figs. 7–8. Wing pronounced.

P. reticulatum (Blake) (sub *Arca*), Quart. Journ. Geol. Soc., vol. xxxi, p. 229, pl. xii, fig. 11. Lower Kim. Clay, Market Rasen. Wing small but definite.

P. nobilis (Contejean) (sub *Arca*), Étage Kim. Montbéliard, 1859, p. 294, pl. xvii, figs. 14–17. Pterocerian. Closely allied to *P. rugosum.*

P. macropygum (Cont.) (sub *Arca*), op. cit., p. 295, pl. xvi, figs. 5–8. Pterocerian. Closely allied to last.

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[1] 1912, "Fossiles nouveaux ou peu connus du Jura, etc.," *M.S. Pal. Suisse*, vol. xxxviii, p. 56.

Corallian and Oxfordian Species.

P. greppini, nom. nov. for *Arca transversa* Greppin, Couches corall. d'Oberbuchsiten, p. 62, pl. iv, fig. 7, non *Arca aemula* var. *transversa* Mor. and Lyc., 1853 = *P. transversum* (Mor. and Lyc.) Bathonian. (Hinge not shown, but shape right.)

P. bipartitum (Roemer) (sub *Arca*), Verst. Nord-deutsch. Oolith. Geb., p. 102, pl. xiv, fig. 12. Figured with synonymy by de Loriol, Couches corall. inf. Jura Bernois, p. 273, pl. xxx, figs. 1–6, and by Buvignier, Stat. géol. Meuse, Atlas, pl. xvi, figs. 1–3. This species is not always alate (see de Loriol's figures).

P. pencki (Boehm) (sub. *Arca*) Kelheimer Diceraskalk, Palaeontographica, vol. xxviii, p. 87, pl. xiii, figs. 3–4.

Bathonian Species.

P. rugosum (Buckman) (sub. *Macrodon*), Outline Geol. Chelt., Appendix to edit. II, p. 99, pl .v, fig. 5. Figd. sub *Macrodon hirsonensis* (non d'Archiac) by Morris and Lycett, Mon. Moll. Great Oolite, p. 49, pl. v, 1, 1*a*, 1*b*. Renamed *Parallelodon* (*Beushausenia*) *Minchinhamptonensis* by Rollier, 1912, Fcss. nouv. ou peu connus du Jura, p. 56. This name holds good if Munster's *Arca rugosa*, 1841, Beitr. zur Petrefact., vol. iv, p. 82, pl. viii, fig. 3, proves to be a *Parallelodon. Arca Kilverti* Mor. and Lyc., op. cit., p. 45, pl. v, fig. 10 (holotype in Mus. Pract. Geol.) was founded on a single incomplete specimen and seems to be a young example of the same species, but is too uncertain for priority.

P. rudis (Sowerby) (sub *Cucullaea*), Min. Conch., vol. v, p. 68, pl. CDxlvii, fig. 4. Refigured (sub *Arca*) by Mor. and Lyc., loc. cit., p. 44, pl. v, fig. 12.

Bajocian Species.

P. lotharingicum Rollier, Foss. nouv. ou peu connus du Jura, 1912, p. 56, nom. nov. for *Macrodus hirsonensis* Benecke, 1905, Verst. Eisenform. Deutsch-Lothringen, Abh. Els.-Loth., p. 176, pl. xiii, figs. 8, 8*a*. Zone of *Sonninia Sowerbyi* (*Sauzei* zone). Closely allied to *P. rugosum.*

Sub-genus BEUSHAUSENIA Cossmann, 1897.

Type: *P.* (*B.*) *hirsonensis* (d'Archiac); not alate.

Portlandian Species.

P. (*B.*) *menandellensis* (de Loriol) (sub *Arca*) 1867, Mon. étage Portlandien Boulogne sur Mer, p. 88, pl. viii, fig. 6.

P. (*B.*) *autissiodorensis* (Cott.) (sub *Arca*), Figd. de Loriol, 1868, Mon. étage Portlandien du dépt. de l'Yonne, p. 179, pl. xi, figs. 6–7.

P. (*B.*) *catalaunicum* (de Lor.) (sub *Arca*), 1872, Mon. étages Jurass. sup. du dépt. de la Haute Marne, p. 325, pl. xviii, figs. 15–16.

Kimeridgian Species.

P. (*B.*) *lutugini* (Borissjack) (sub *Macrodon*), Pelec. Jura. Ablag. Europ. Russland ; Arcidae, pl. i, figs. 10–12, 16–18. Volgian of central Russia.

P. (*B.*) *productum* (Rouillier), figd. Borissjack (sub *Macrodon*), loc. cit., pl. i, figs. 14–15. Volgian of Central Russia.

P. (*B.*) *compressiusculum* (Rouillier), figd. Borissjack (sub *Macrodon*), loc. cit., pl. ii, fig. 7. Volgian of Central Russia.

P. (*B.*) *sublatum* (d'Orb.) nom. nov. for *Arca langii* Contejean, Étage. Kim. Montbéliard, p. 293, pl. xvi, figs. 9–12 (non Thurmann). Pterocerian.

P. (*B.*) *cruciatum* (Contej.), loc. cit., p. 290, pl. xvii, figs. 10–11. Virgulian. Refigd. de Loriol, 1872, Mon. Haute Marne, p. 329, pl. xviii, figs. 15–16.

Corallian, Oxfordian, and Callovian Species.

P. (*B.*) *burensis* (de Lor.) (sub *Arca*), Couches Séquan. Tonnerre, p. 123, pl. viii, fig. 15, and Couches corall. inf. Jura Bernois, p. 278, pl. xxx, fig. 12. Sequanian.

P. (*B.*) *ceres* (Sauvage) (sub *Arca*), figd. de Loriol, 1874, Étages jurass. sup. de Boulogne sur Mer, p. 147, pl. xviii, fig. 9. Sequanian.

P. (*B.*) *aemulum* (Phillips) (sub *Arca*), Geol. Yorks., pl. iii, fig. 29 ; and Geol. Oxford, pl. xiii, fig. 31. Refigd. Arkell, Mon. Corall. Lamell., pl. i, figs. 7–10. Argovian and Rauracian. A much misinterpreted species.

P. (*B.*) *luxdorfensis* (de Lor.) (sub *Macrodon*), Oxfordien sup. moy. Jura Bernois, p. 112, pl. xiv, figs. 12–14, and Ire. Supplt., pl. v, figs. 15–17 ; nom. nov. for *Macrodon* cf. *elongatus* Roeder, Terrain à Chailles Umgeg. von Pfirt, p. 67, pl. i, fig. 6. Lo. Calc. Grit.

P. (*B.*) *keyserlingii* (d'Orb.), Prod. Pal., i, p. 369, nom. nov. for *Arca elongata* Keyserling, Reise in Petschora Land, p. 304, pl. xvii, figs. 1–4. Figd. with hinge by Borissjack, loc. cit., pl. i, figs. 5–9 ; by Lahusen, 1883, pl. ii, figs. 14–15, and by Boden, 1911, pl. vii, figs. 9, 9*a*, Oxfordian of Russia and elsewhere.

P. (*B.*) *fischeri* (d'Orb.), Prod. Pal., i, p. 369, nom. nov. for *Arca concinna* d'Orb., Géol. de la Russie, 1845, vol. ii, p. 462, pl. xxxix, figs. 17–18. Oxfordian of Russia.

P. (*B.*) *franconensis* nom. nov. for *Arca elongata* Goldfuss, 1837, Petrefacta Germaniae, p. 148, pl. cxxiii, figs. 9*a*–*c* (shows hinge). Oxfordian of Franconia.

P. (*B.*) *rouillieri* (Lahusen), figd. by Borissjack (sub *Macrodon*), loc. cit., pl. ii, figs. 1–5. Oxfordian and Kellaways of Russia.

Bathonian and Vesulian Species.

P. (*B.*) *hirsonensis* (d'Archiac) (sub *Cucullaea*) Mém. Soc. Géol. France [I], vol. v, 1842, pl. xxvii, figs. 5, 5*a* (shows hinge well). Vesulian of the Aisne.

P. (*B.*) *transversum* (Mor. and Lyc.), figd. sub. *Arca aemula* (non Phill.) var. *transversa* Morris and Lyc., Mon. Moll. Great Oolite, 1853, p. 47, pl. v, fig. 8. Upper Bathonian, Minchinhampton, Glos. Holotype in Mus. Pract. Geol. No. 9199.

Bajocian Species.

P. (*B.*) *rasilis* (Whidborne) (sub *Macrodon*), Quart. Journ. Geol. Soc., vol. xxxix, p. 521, pl. xvi, figs. 15, 15*a–b*. Closely related to the Liassic *P. Buckmani*. Inferior Oolite, Bradford Abbas, Dorset.

P. (*B.*) *verevkinense* (Borissjack) (sub *Macrodon*), loc. cit., pl. i, figs. 1–3. Bajocian of Donetz Basin, etc.

Liassic Species.

P. (*B.*) *buckmani* (G. F. Richardson) (sub *Macrodon*), in Buckman, Supplt. to Murchison, Outl. Geol. Cheltenham, 2nd ed., 1845, p. 96, pl. x, fig. 5. Figd. L. Richardson (sub *Macrodon*), Handb. Geol. Cheltenham, pl. xv, fig. 9. *Davoei* (*Capricornu*) zone of most of England.

P. (*B.*) *bonneti* (Choffat) (sub *Macrodon*) Faune Jurass. Portugal, p. 57, pl. xi, figs. 43–6. Lias of Algarve, Portugal.

P. (*B.*) *hettangiensis* (Terquem) (sub *Cucullaea*), Mém. Soc. Géol. France [2], vol. v, 1855, p. 308, pl. xxi, figs. 3*a* and *b*. Lo. Lias, Hettange. Figd. (sub *Nemodon*) by Cossmann, 1903, Bull. Soc. Géol. Fr. (IV), vol. iii, p. 517, pl. xvii, figs. 11–12.

P. (*B.*) *similis* (Terq.) (sub *Cucullaea*), loc. cit., p. 308, pl. xxi, figs. 2*a* and *b*. Lo. Lias, Hettange.

P. (*B.*) *banburyensis* (Seeley, M.S.). from the *davoei* zone of the Lower Lias, Banbury, Oxon.

Dentition : Three anterior teeth, merging into about three obscurely differentiated granules beneath the umbones, and three elongated posterior teeth, the innermost interrupted throughout most of its length.

Form : Rounded elongate-oblong, with rounded postero-ventral angle ; unusually compressed, with very narrow ligament area, the umbones being almost contiguous. Ornament consists of fine, smooth, concentric ribs, between which faint radial striae are discernible only towards the margin.

Sub-genus GRAMMATODON Meek, 1860.

Type : *G. inornatum* Meek.

Kimeridgian Species.

P. (*G.*) *schourovskii* (Rouillier), figd. Borissjack (sub *Macrodon*), loc. cit., pl. ii, figs. 10–14. Volgian of Central Russia.

Corallian and Oxfordian Species.

P. (*G.*) *rhomboidalis* (Contejean) (sub *Arca*), figd. de Loriol and Pellat, Étages Jurass. sup. Boulogne sur Mer, p. 144, pl. xviii, figs. 2–3 (shows dentition). Sequanian to Virgulian.

P. (*G.*) *montanayensis* (de Loriol) (sub *Macrodon*), Oxfordien sup. moy. Jura Bernois, Ire. supplt., pl. v, figs. 12–14 (shows dentition). Also in Kent borings (sub *Grammatodon*).

P. (*G.*) *alsaticum* (Roeder) (sub *Macrodon*), Terrain à Chailles Umgeg. von Pfirt, p. 68, pl. iii, fig. 2, and de Loriol, Oxf. sup. moy. Jura Bernois, Ire. Supplt., pl. v, figs. 11, 11*a* (shows dentition).

P. (*G.*) *concinnum* (Phillips) (sub *Cucullaea*), Geol. Yorks., pl. v, fig. 9. Oxford Clay. Holotype in Yorkshire Mus. refigured, with hinge, by de Loriol (sub *Macrodon*), loc. cit., p. 109, pl. xiv, figs. 5–11. Also found in the Kent borings (sub *Grammatodon*).

? *P.* (*G.*) *subparvulum* (d'Orb.) (sub *Cucullaea*) as figd. by Choffat, 1888, Faune Jurass. Portugal, p. 52, pl. xi, figs. 25–9. Upper Oxfordian (Lusitanian) of Portugal.

P. (*G.*) *pictum* (Milasch), figd. Borissjack (sub *Macrodon*), op. cit., pl. ii, figs. 16–19, and pl. iii, figs. 1, 2, 6. Oxfordian to Sequanian. Punctate ornament like *Arca striato-punctata* Terq. and Jourdy.

P. (*G.*) *gagnebini* (de Lor.), figd. Borissjack (sub *Macrodon*), op. cit., pl. iii, fig. 3. Lo. Oxfordian.

Bathonian Species.

P. (*G.*) *stockari* (Moesch) (sub *Arca*), Beitr. Geol. Karte Schweiz, iv, 1867, p. 305, pl. v, figs. 11*a–c*. Bathonian of the Canton of Zurich. (Hinge well shown.)

? *P.* (*G.*) *striato-punctatum* (Terquem and Jourdy) (sub *Arca*), Bathonien de la Moselle, p. 113, pl. xii, figs. 9–12. Among *Isastraean* corals at les Clapes. Hinge not seen, but ornament recalls *P.* (*G.*) *pictum* (Milasch).

? Bajocian Species.

P. (*G.*) *goldfussi* nom. nov. for *Arca concinna* Goldf., Pet. Germ., p. 148, pl. cxxiii, figs. 6*a* and *b*, from the Inferior Oolite of Pappenheim and Rabenstein. Shorter than and differently ribbed from *G. concinnum* (Phil.) from the Oxford Clay.

Liassic Species.

P. (*G.*) *inornatum* Meek and Hayden, 1860, Proc. Acad. Nat. Sci., Philadelphia, p. 51 ; and 1864, Pal. Upper Missouri, p. 90, pl. iii, figs. 9*a–c*. Black Hills, Dakota. Genotype.

P. (*G.*) *intermedium* (Simpson) (sub *Arca*). Fossils of the Yorkshire Lias, 1884, p. 185. Figd. Richardson, 1904, Handbook Geol. Cheltenham, pl. xiv, figs. 2*a* and *b*. *Davoei* zone, Cheltenham and Yorkshire.

P. (*G.*) *chapuisi*, nom. nov. for *A. elegans* Chapuis and Dewalque Descr. Foss. second. Luxembourg, p. 178, pl. xxiv, figs. 2*a–e*. Lias, Grand-Cour, Luxembourg. Hinge of *Grammatodon* ; ornament of left valve consists of widely-spaced radial ribs all over. Probably not Roemer's sp., 1836, Verst. Nord-Oolith, Geb., pl. vi, fig. 16, which is probably a *Cucullaea*.

P. (*G.*) *inaequivalvis* (Goldfuss) (sub *Arca*), Petref. Germaniae, p. 146, pl. cxxii, figs. 12*a–d*. Lias of Wurtemberg and Bamberg. L. valve more strongly ribbed than the right. Hinge well shown. General appearance extremely like *G. securis* (Leymerie) from the zone of *Bel. brunsvicensis* in the Speeton Clay, figd. Woods, 1899, loc. cit., pl. vii, figs. 14–15.

? *P.* (*G.*) *lineatum* (Goldfuss) (sub *Arca*), Petref. Germaniae, p. 141, pl. cxxi, figs. 9*a–c*. Lias of Wurtemberg. Shows faint ribbing on posterior and anterior ends of right valve. Left valve not shown.

P. (*G.*) *chartroni* (Cossmann) (sub *Nemodon*), 1903, Bull. Soc. Géol. Fr. (IV), vol. iii, p. 515, pl. xvii, figs. 5–7. Lo. Lias, Simon-la-Vineuse, la Vendée.

Sub-genus CATELLA Healey, 1908.

(Pal. Indica, N.S., vol. ii (Mem. 4), p. 13.)

Type : *Grammatodon* (*Catella*) *laticlava* Healey.

Valves short at the anterior end, high and produced at the posterior end, characterized by a strong internal rib, which divides the umbo into two nearly equal parts and continues downwards, usually dying out just before reaching the ventral margin. The position of the rib is marked externally by a shallow mesial sulcus, and it leaves a deep groove on the internal cast. Dentition and other features as in *Parallelodon*.

Liassic and Rhaetic Species.

P. (*C.*) *laticlava* Healey, 1908, loc. cit., p. 13, pl. i, figs. 20–3. Rhaetic of Upper Burma. Genotype.

P. (*C.*) *trapezium* (Cox), 1928 (sub *Parallelodon*), Quart. Journ. Geol. Soc., vol. lxxxiv, p. 240, pl. xviii, figs. 5*a* and *b*. Belemnite Marls of the Lower Lias, Charmouth, Dorset. Mr. Cox says that a similar undescribed species occurs in the Upper Lias of Lincoln.

Triassic Species.

Several species assignable to *Catella* have been described under various generic names from the Trias, e.g. *Macrodon* (*Cucullaea*) *laubei* Broili and *impressa* (Münst) in Broili's " Fauna der Pachycardientuffe der Seiser Alp ", Palaeontographica, 1904, vol. l, pl. xxiv, figs. 30–2. For other references to all Triassic Arcidae described up to 1923 see C. Diener, " Lamellibranchia triadica," Fossilium Catalogus, I, Animalia, pars. 19.

VII. NAVICULA AND EONAVICULA.

We have already noticed that several of the species described by Morris and Lycett in their Monograph as *Arca* can be classed as neither *Parallelodon*, *Grammatodon*, *Beushausenia*, *Barbatia*, *Cucullaea*, nor *Isoarca*; namely, *A. eudesii* Mor. and Lyc., *A. minuta* Sow., and *A. aemula* Mor. and Lyc. non Phil. (*A. aemula* Phil. is a *Beushausenia*).

These belong to a very distinct genus, having a thin, straight hinge-plate, a wide ligament area, a high, acute, undercut carina with several deep radial grooves posterior to it, and anterior, distant umbones, obliquely flattened on their anterior side. The surface is usually covered with numerous fine radial ribs, and there is a wide gape in the ventral margin. The type is common throughout the Jurassic, and appears in the works of many authors, usually as *Arca*, but sometimes variously as *Cucullaea*, *Parallelodon*, and *Barbatia*.

It is only occasionally that the hinge and teeth are visible and they have rarely been figured. Nevertheless, in one of the earliest published figures of an *Arca* of this group, that of *Arca fracta* Goldfuss [1] from the coral rag of Nattheim (almost certainly the same species as *A. trisulcata* Goldf. from the same horizon and locality) foreshortened views of the dentition are portrayed, from which it is apparent that the hinge-plate is much thinner than in *Parallelodon* or *Cucullaea*, or their sub-genera, and bears towards *both* ends a series of short, oblique, dorsally-divergent teeth.

As late as 1892 de Loriol, in figuring another Corallian species, *A. bourgueti*, was puzzled by the dentition, which he said was that of *Barbatia* and not that of *Macrodon*. While likening it to *A. quadrisulcata* Sow. in all other ways (the dentition of *A. quadrisulcata* Sow. being unknown but presumed to be that of *Macrodon*) he classed it definitely as a *Barbatia*.[2] That this must have caused so acute an observer as de Loriol considerable uneasiness, to say the least of it, is evident from a comparison of the accompanying figures of the exterior with any known species of *Barbatia*. There is no resemblance whatever. Moreover, on the same plate he figured another species, closely allied, as a *Macrodon*, (*Arca* (*Macrodon*) *cepha* de Lor).

In 1897 another species was described by de Loriol as *trichordis*, in reference to the radial grooves behind the carina, and this time beautiful figures of the hinge and interior were given.[3] These show a thin, narrow, straight hinge-plate, bearing a series of short, oblique, dorsally divergent, transverse teeth, about six on each side of the umbo, beneath which they are linked up by a series of minute teeth, decreasing in size to mere granules in the centre. The interior shows no raised lamina or boss for the attachment of either anterior or posterior adductor (Pl. XVI, Fig. 4).

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[1] 1837, *Petrefacta Germaniae*, p. 141, pl. cxxi, figs. 11*b* and 10*a*.

[2] 1892, "Ét. sur les moll. des Couches coralligènes inf. Jura Bernois," *M.S. Pal. Suisse*, p. 282, pl. xxx, fig. 16.

[3] 1897, "Ét. sur les moll. de l'Oxfordien sup. et moy. du Jura Bernois" (part 2), ibid., p. 107, pl. xiv, figs. 4 *a–c*.

This time de Loriol remarks that the hinge is " in a sense intermediate between that of *Barbatia* and that of *Cucullaea*, but to be likened rather more to *Cucullaea* ". While classing it as a *Cucullaea* for descriptive purposes, he comments on the absence of a raised posterior muscle attachment, but says that this may possibly have been removed (loc. cit., p. 108).

Quite recently Mr. L. R. Cox, as has been remarked, described as *Parallelodon dorsetensis* another species, from the Portlandian, giving a drawing of the dentition.[1] Two years later, following him and the new Kent Survey Memoir,[2] I classed the allied *Arca quadrisulcata* Sow. also as a *Parallelodon*.[3] At the same time I felt considerable misgivings as to the correctness of this identification, this peculiar type of dentition being quite different from that of *Parallelodon*, and always being accompanied by the distinctive shell features already enumerated, equally different from the shell features of *Parallelodon* or its sub-genera, but strongly suggestive of *Arca sensu stricto* (*olim.*). Indeed, a close comparison of *A. quadrisulcata* Sow. with such recent species as *A. ventricosa* Lamk. (see Figs. 19–22) reveals an exact agreement in shape, form and position of umbones, form of carina, with radial grooves behind it, shape and thinness of hinge-plate, ventral gape, style of ribbing, and in fact every character except the teeth. The teeth of the recent species are more numerous, more equal, shorter, and vertically directed (Figs. 15–17 and Pl. XVI).

When we examine Eocene species, however, we find in some a tendency for the teeth to become oblique, diverging dorsally away from the umbones, e.g. *Arca laudunensis* Deshayes,[4] *A. altera* Desh.,[4] and *A. hiantula* Desh. (Pl. XVI, Fig. 1). In certain Cretaceous species this is scarcely perceptible, e.g. *A. dupiniana* d'Orb. (Pl. XVI, Fig. 2), but in others, such as *A. carteroni* d'Orb. (Pl. XVI, Fig. 3) from the Lower Greensand, there is a perfect transition to the more widely-splayed teeth of the Jurassic species (compare series of figures, Pl. XVI, Figs. 1–4 and Text-figs. 15–17).

I have recently been able to study the hinge of the holotype of *A. eudesii* Mor. and Lyc. from the Great Oolite (Bathonian) (Fig. 17) and find that the teeth are definitely more elongate and oblique than in those higher Jurassic species of which the hinge is known, *A. dorsetensis* Cox and *A. trichordis* de Lor.

From these facts I am led to conclude that the multiple, vertical, equal teeth of the modern *Arca s. s.* developed from the Jurassic type as seen in *A. eudesii*, etc., and the similarity, sometimes virtual identity, of the shell characters of these Jurassic forerunners demands that they should not be separated any more than in a sub-genus.

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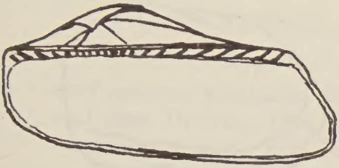
[1] 1925, *Proc. Dorset F. C.*, vol. xlvi, p. 128, pl. i, figs. 7*a* and *b*, and pl. ii, figs. 1*a*, *b*, and 2.

[2] 1923, op. cit., p. 95.

[3] 1927, *Phil. Trans. Roy. Soc.*, vol. ccxvi, B, pl. ii, fig. 8.

[4] Figured by Deshayes, 1860, op. cit., vol. i, atlas, pl. lxix, figs. 11 and 15.

Those who have recently visited the shell gallery at the British Museum of Natural History (South Kensington) where Mr. J. R. le B. Tomlin has been revising and rearranging the collections, will be familiar with the restriction of the name *Arca* Linnaeus to the curious twisted shells of the *tortuosa* group, formerly known as *Parallelepipedum* Klein. The reason for this is that the species *A. tortuosa* Linn. was the first to be described as *Arca* by Linnaeus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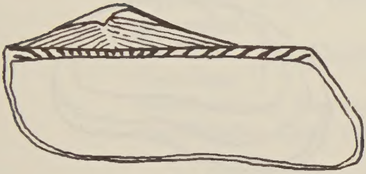
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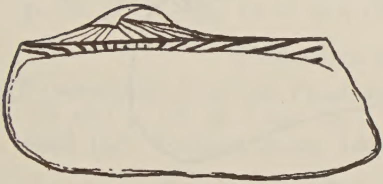
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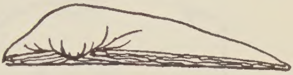
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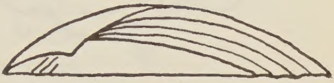
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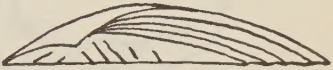
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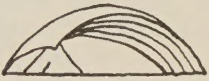
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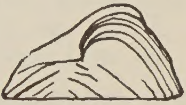
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FIGS. 15–17.—Species of *Eonavicula*, showing the hinge.

FIG. 15.—*N.* (*E.*) *carteroni* (d'Orb.), Lower Greensand (after Woods, *Mon. Cret. Lamell.*, pl. i, fig. 5b).

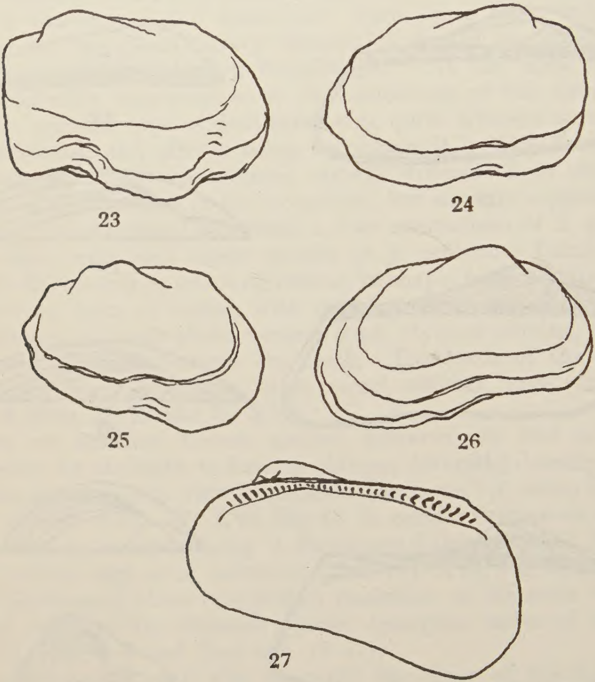
FIG. 16.—*N.* (*E.*) *dorsetensis* (Cox), Portlandian (the dentition after Cox, *Proc. Dorset F.C.*, vol. xlvi, pl. i, fig. 7a, from a paratype).

FIG. 17.—*N.* (*E.*) *eudesii* (Morris and Lycett), Great Oolite and Forest Marble (drawn from the holotype).

FIGS. 18–22.—Comparison of the dorsal view of *Parallelodon*, *Navicula*, and *Eonavicula*.

Fig. 18.—*P. buckmani* Fig. 19.—*N.* (*E.*) *quadrisulcata*. Figs. 20–2.—*N. squamosa*. Figs. 20–2 represent three individuals from a beach on the Red Sea, and show the wide variation in tumidity.

in the tenth edition of the *Systema Naturae*, and so has prior claim to the name. The Recent form we have been discussing, formerly known as *Arca sensu stricto*, must now be named *Navicula* Blainville, the type of which is the living *Navicula noœ*.[1] For this reason I have named the new sub-genus, to receive these Jurassic forerunners, *Eonavicula*, with the first species to be described and figured, the Corallian *Arca quadrisulcata* Sow., as type.[2]



Figs. 23–7.—*Barbatia helblingi* (Brug.), showing deformation connected with coral reef habitat. From a raised Pleistocene reef, Qosseir, Red Sea.

It is perhaps worthy of note that, like the modern *Naviculae*, species of *Eonavicula* are subject to great distortion and deformity. It is almost impossible to obtain two specimens of *N.* (*E.*) *quadrisulcata* exactly alike in shape. I have recently figured three specimens which, in the absence of other material, might be supposed to represent three species.[3] Figs. 20–2, which I insert for comparison, represent in the form of outline drawings a series of *N. squamosa.*

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[1] 1825, de Blainville, in *Dict. Sci. Nat.*, vol. xxxiv, p. 319, pl. xci, fig. 2.
[2] 1929, Mon. Brit. Corallian Lamellibranchia, *Pal. Soc.*, p. 36.
[3] 1929, loc. cit., pl. i, figs. 3–5.

collected from a beach on the coast of the Red Sea. The same distortion is noticeable in certain species of *Barbatia*, and may be connected with their common coral reef habitat (see Figs. 23–27).

VIII. SPECIES OF EONAVICULA.

So much confusion has arisen concerning the naming of these shells in the past that it may be useful to give a list of those species the identity of which can be established beyond doubt.

Genus NAVICULA Blainville, 1825.

Type: *N. noë* (Linn.).

= *Byssoarca* Swainson, 1833, Proc. Zool. Soc., p. 16.
= *Cibota* Browne, Hist. Jamaica (pre-Linnean).
= *Arca s.s. auct.*, non Linnaeus.

Sub-genus *Eonavicula* Arkell, 1929.

Synonyms: *Arca* Sowerby, 1825, et auctt.
Byssoarca King, 1850.
Macrodon, *Barbatia*, *Cucullaea* } de Loriol (various dates).
Grammatodon (Survey, 1923).
Parallelodon Cox, 1925, Arkell, 1927.

Lower Cretaceous Species.

N. (*E.*) *carteroni* (d'Orb.) (sub *Arca*), Pal. Franc. Terr. Crét., vol. iii, p. 202, pl. cccix, figs. 4–8; and figd. Woods, Mon. Cret. Lamell., p. 33, pl. vi, figs. 4*a*–*c*, 5*a*–*c* (Pl. XVI, Fig. 3).

Portlandian Species.

N. (*E.*) *dorsetensis* (Cox) (sub *Parallelodon*). Proc. Dorset Field Club, vol. xlvi, p. 128, pl. i, figs. 7*a*, *b*, and pl. ii, figs. 1*a*, *b*, 2. Basal Shell Bed, Portland Stone, Isle of Portland (Fig. 16).

Corallian and Oxfordian Species.

N. (*E.*) *quadrisulcata* (Sow.) (sub *Arca*), Min. Conch., 1825, vol. v, p. 115, pl. cccclxxiii, fig. 1; and figd. Arkell, Phil. Trans. Roy. Soc., vol. ccxvi, B, pl. ii, fig. 8, and Mon. Corallian Lamell., pl. i, figs. 3–5*a*. Foreign examples figd. by de Loriol, (sub *Arca* (*Macrodon*) *cepha* de Lor.), Couches Corall. inf. Jura Bernois, p. 276, pl. xxx, figs. 7–11, and Couches Séquaniens de Tonnerre, p. 121, pl. viii, fig. 14, and (sub *Arca* (*Barbatia*) *bourgueti* de Lor.), Couches Corall. inf. Jura Bernois, p. 282, pl. xxx, fig. 16. (Four radial sulci posterior to the carina). (Pl. XVI, Fig. 8.)

N. (*E.*) *rutimeyeri* (de Lor.) (sub *Arca*), Couches Coralligènes inf. Jura Bernois, p. 287, pl. xxxi, figs. 1–2, figured (sub *Arca quadrisulcata* non Sow.) by de Loriol, Jurass. sup. Boulogne sur

Mer, p. 145, pl. xviii, figs. 7–8, and (sub *Arca quadrisulcata* non Sow.) by Choffat, Faune Jurass du Portugal, pl. xi, figs. 20–3 (three radial sulci posterior to the carina).

N. (*E.*) *trichordis* (de Lor.) (sub *Cucullaea*), Oxf. sup. moy. Jura Bernois, p. 107, pl. xiv, figs. 4, 4*a*. (Three radial sulci.) (Pl. XVI, Fig. 4.)

N. (*E.*) *thurmanni* (Contejean) (sub *Arca*), Étage Kim. de Montbéliard, p. 290, pl. xvii, figs. 1–3. (non de Lor. 1872, Haute Marne, p. 331, pl. xviii, figs. 17–18 = *N.* (*E.*) *rutimeyeri* de Lor. sp.) Astartian of Chatillon. (Two radial sulci.)

N. (*E.*) *fracta* (Goldfuss) (sub *Arca*), Pet. Germ., p. 141, pl. cxxi, figs. 10*a*–*b* (no radial sulci) ; and *Arca trisulcata* Goldf., ibid., p. 142, pl. cxxi, figs. 11*a* and *b*. (Three incipient radial sulci.) Both came from the coral rag of Nattheim and it seems extremely probable that they are variations of one species.

N. (*E.*) *semifracta* (Étall) (sub *Arca*), Ét. pal. sur le Haut Jura, Corall., ii, p. 104 ; figd. de Loriol, Couches Corall. Valfin, p. 289, pl. xxxiii, figs. 8–9. (No radial sulci.) Doubtfully distinct from *N.* (*E.*) *fracta* (Goldf.).

? N. (*E.*) *granulata* (Goldf.) (sub *Arca*), Pet. Germ. p. 149, pl. cxxiii, figs. 10*a* and *b*. Coral rag, Nattheim.

Bathonian species.

N. (*E.*) *eudesii* (Morris and Lycett) (sub *Arca*), Mon. Moll. Great Oolite, 1853, p. 47, pl. v, figs. 6, 6*a* ; and large Forest Marble specimen (deformed) figd. by Lycett, ibid., Suppl., 1863 (sub *Macrodon hirsonensis* var. *rugosa* Lyc.), p. 113, pl. xxxvi, fig. 9, renamed by Rollier *Parallelodon* (*Beushausenia*) *gibbosa*, Foss. nouv. peu connus du Jura, 1912, p. 57 = *Arca Elathea* d'Orb. nom. nud. = *Arca Eudora* d'Orb. nom. nud., Prod. Pal., vol. i, p. 311, figd. 1913, Annales de Pal., pp. 151–2, pl. xxvii, figs. 28, 33, 34. (Pl. XVI, Figs. 6, 7, and text-fig. 17.)

N. (*E.*) *minuta* (Sow.) (sub *Cucullaea*), Min. Conch., vol. v, p. 68, pl. CDxlvii, fig. 3 ; and figd. Mor. and Lyc., 1853, op. cit., p. 48, pl. v, fig. 11, and pl. vi, fig. 19. Probably the same as *Arca aemula* Mor. and Lyc. (non Phil.), loc. cit., p. 47, pl. v, fig. 17, and *? Macrodon aemulum* Greppin, Grande Oolithe de Bale, p. 114, pl. viii, fig. 11. ? = *Arca Echo* d'Orb., Prod. Pal., vol. i, p. 310. (Pl. XVI, Fig. 5.)

? Bajocian Species.

? N. (*E.*) *aequata* (Whidborne) (sub *Arca*), Quart. Journ. Geol. Soc., vol. xxxix, p. 520; pl. xvi, fig. 14. *Murchisoni* freestone, Leckhampton, Glos.

IX. THE ORIGIN OF NAVICULA AND EONAVICULA.

The stability of shell characters, combined with plastic dentition, which has characterized the genus *Navicula* throughout the Mesozoic, Tertiary, and Recent, is one of the most remarkable evolutionary histories known among the lamellibranchs.

Parallelodon and its sub-genera seem to have kept the same shell characters (except for a thickening in some species under the anterior adductor attachment) from at least as early as the Middle Devonian until the end of the Jurassic, but the hinge features also remained unchanged.

I have not succeeded in tracing any certain representatives of *Eonavicula* in either the Lias or the Trias. In the Permian, however, the characteristic shell features appear in three Magnesian Limestone species figured by King as *Byssoarca tumida*, *B. striata*, and *B. kingiana*.[1] It is apparent that King did not fail to notice the resemblance between these species and the modern *Navicula*, for in naming them *Byssoarca* he sought to correct the current error of referring such species to *Arca* Linn. *s. s.*, which he pointed out should be restricted to *Arca tortuosa* Linn. (*Byssoarca* Swainson (1833) is a synonym of de Blainville's name *Navicula*, 1825.) There is, indeed, no possibility of confusing these Permian species with *Parallelodon* if we note the external features, particularly remarking the dorsal views shown by King.

Unfortunately the dentition is somewhat doubtful. Several short, oblique, anterior teeth are distinctly shown; but the posterior teeth are obscure. Only the posterior three are visible, but these are shown to be elongate, and to diverge dorsally in a posterior direction. This is the opposite direction to that taken by the elongate posterior teeth of *Parallelodon*. The dentition is, therefore, so far as it can be seen, distinctly more like that of *Eonavicula* than that of *Parallelodon*, though the posterior teeth are perhaps more elongate.

In the Carboniferous rocks, where *Parallelodon* was so numerous, we look in vain for *Eonavicula*. At least, no species that could be attributed to it are figured in Wheelton Hind's monograph, and I have not succeeded in finding any examples portrayed while searching in a number of foreign works on the Carboniferous.

The same may be said of *Barbatia*, Gray, which can be traced down from the present time through the Jurassic, the same in dentition and shell features, to the Lower Lias, where it is represented by *B. pulla* (Terquem).[2] Some Triassic species can certainly be identified with it, although the hinge-features of most still remain to be adequately figured. *Barbatia* is probably the stock from which the similar living and Tertiary genera *Anadara*, *Argina*, *Scapharca*, *Senilia*, etc.,[3] sprang, probably *via* the Cretaceous genus *Nemoarca* Conrad.[4]

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[1] 1850, "Mon. Permian Foss. England," *Pal. Soc.*, pp. 172, 173, and pl. xv, figs. 1–12.

[2] 1855, "*Arca pulla* Terq.," *Mém. Soc. Géol. France*, [2] vol. v, p. 307, pl. xxi, figs. 1*a* and *b*.

[3] All founded by Gray.

[4] 1870, *Am. Journ. Conch.*, vol. v, p. 97 (*nomen nudum*), figd. 1885, Whitfield, loc. cit., pl. xii, figs. 8–10.

Barbatia and *Eonavicula* have far more in common in respect of their hinge than either has with *Parallelodon* or *Cucullaea*, in that in both, the posterior and anterior teeth are relatively short and homogeneous (i.e. evenly graded) and diverge dorsally away from the umbones throughout life (Fig. 27).

From these considerations we may surmise that *Eonavicula* and *Barbatia* had a common (and truly taxodont) ancestor, possibly in the Ordovician or earlier. At this time several peculiar taxodont shells existed, too large and not of the right shape for the Nuculid genus *Ctenodonta*, to which they have sometimes been assigned, e.g. *Arca edmondiiformis* McCoy,[1] and *Arca naranjoana* de Verneuil, the latter a constituent of the Budleigh Salterton Pebble beds.[2]

A taxodont genus has been described from the Upper Carboniferous under the name *Carbonarca* by Meek and Worthen.[3] This genus has a large number of minute teeth, of which the two most anterior are stouter than the rest, and oblique. The shape of the shell at once suggests *Isoarca*, from which it only seems to differ by the enlargement of the two anterior teeth, and of which it may well be a forerunner. *Isoarca*, which became extinct in the Cretaceous, has little in common with the Arcidae, and on the grounds of shell structure it has been suspected of closer affinity with the *Nuculidae*.[4] An Ordovician shell bearing a remarkably close resemblance to *Isoarca* was figured by Sedgwick and McCoy as *Arca subaequalis* McCoy [5] (since sometimes referred to *Ctenodonta*).

In passing, reference must be made to the genus *Sphenotus* Hall,[6] some species of which bear a striking resemblance externally to *Navicula*. *Sphenotus* as defined by its author has a narrow hinge-plate, bearing two short, narrow, sub-umbonal teeth and one or two extremely slender lateral teeth. The ligament is external, contained in a slender groove along the cardinal line, and the pallial line is simple. This definition of the hinge does not suffice to place it in its correct systematic position, but it is enough to show there can scarcely be any affinity with the Taxodonta. Hall placed it in the *Sanguinolitidae*, usually known as the *Solenopsidae*, but Zittel classes it among the Astartidae,[7] a sufficient indication of its problematic character. A similar shape, suggestive of *Navicula*, is seen in certain species of *Goniophorus*, the hinge of which is figured by Hall, and is seen to bear only a single, large sub-umbonal tooth.[1] We may safely conclude, therefore, that this resemblance to *Navicula*, though striking, is fortuitous and of no phylogenetic significance.

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[1] 1855, Sedgwick and McCoy, *Brit. Pal. Foss.*, pl. 1*k*, fig. 3.

[2] 1855, *Bull. Soc. Géol. France* [2], vol. xii, p. 989, pl. xxvi, fig. 12. But this may possibly be an early *Beushausenia*.

[3] 1870, *Proc. Acad. Nat. Sci. Philadelphia*, p. 39, and defined 1875, *Geol. Surv. Illinois*, vol. vi, p. 530.

[4] See Stoliczka, 1871, loc. cit., p. 339.

[5] 1855, Sedgwick and McCoy, loc. cit., pl. 1*k*, figs. 1–2.

[6] 1885, *Geol. Surv. State of New York*, loc. cit., p. xxxiii, type *Sanguinolites arcaeformis* Hall, pl. lxv, figs. 7–11, and see numerous figures on pls. lxv, lxvi.

[7] 1924, loc. cit., p. 380.

X. GENERAL REMARKS.

The history of the development of *Eonavicula* and *Navicula*, traced in the foregoing pages, shows a progressive accentuation of the taxodont character of the dentition by a steady multiplication of teeth and proportionate diminution in their size. The large number of species by which *Navicula* is now represented is testimony that the modification has been a favourable one.

At the present day the Arcidae in overwhelming majority are those in which the dentition conforms most strictly to the taxodont plan. The proportion of species with a divergent type is negligible, comprising only a few rare species of *Cucullaea* and the solitary little Japanese *Pseudogrammatodon dalli*, apparently representing a retrograde offshoot from *Barbatia*.

This state of affairs is very different from that prevailing in the Mesozoic period. Then the number of Arcidae with truly taxodont dentition was more than equalled by the number of those in which either the posterior only, or both the posterior and anterior, teeth were elongate (grouped together by Meek and Hayden in a subfamily, the Macrodontinae which must now be known as the Parallelodontinae). *Navicula* had not yet perfected fully taxodont dentition, and, in the form of *Eonavicula*, was in a condition intermediate between the two types. If a census of species and individuals could have been taken in the Jurassic, *Barbatia* and *Limopsis* would certainly have been far outnumbered by *Parallelodon*, *Beushausenia*, *Grammatodon*, *Catella*, and *Cucullaea*.

In the Carboniferous and Devonian periods the position was the reverse of that obtaining at the present day, for *Parallelodon* and *Beushausenia* held the field almost without a rival.

In contrast to this waning and waxing among the genera of the Arcidae, it is interesting to notice the history of the most typical taxodont family, the Nuculidae, which has persisted with little modification or fluctuation in numbers from at least Ordovician times until the present day.

The inference which we cannot fail to draw is that the taxodont type of dentition has a mechanical advantage over the longitudinal arrangement of the teeth, and has enabled the genera which developed it to achieve conspicuous biological success. This seems the most satisfactory explanation of the extinction of most of the genera of the Parallelodontinae, after an era of dominance in the Upper Palaeozoic. We cannot but remark also the short-lived career of *Nemodon*, which developed elongate anterior as well as posterior teeth, and the rapid extinction of the most extreme manifestation of the longitudinal type of dentition, the genus *Cucullaria*.

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[1] 1885, loc. cit., pl. xliv, fig. 14.

Sharply contrasted with these is the meteoric and comparatively recent success of *Navicula*, the steady increase of *Barbatia* from the Trias onwards, and the rapid evolution of a number of successful genera from the *Barbatia* stock since the beginning of Cretaceous and even Tertiary times.

The Ontogeny of Certain Arietidan Oxycones.

By T. Neville George, M.Sc., Ph.D., F.G.S., University College of Swansea.

I. Introduction.

The compressed angustumbilicate oxycones of the Deiran and Raasayan stages of the Lower Lias are generally assumed to be " homoeomorphous terminals of different lineages "[1] of the Arietidae. But while the characters of the adult sutures of these forms link them with that family, there is comparatively little evidence as to the details of the ontogenetic developments of the various genera hitherto recognized. It is the purpose of this paper to repair this deficiency in some slight measure. The two forms selected, partially for convenience, are of considerably different ages : *Victoriceras* is a Raasayan form, while *Oxynoticeras oxynotum* occurs at a considerably lower horizon in the Deiran.

II. The Development of Victoriceras victoris (Dumortier).

This species occurs commonly in the *armatum* Bed of the Lower Lias in the Radstock district, where it is associated with later Echioceratidae.[2]

Sutural Characters. (Figs. 1*a*–*h*.)

The first suture is of typical angustisellate pattern. In the second, the external lobe is very considerably developed, but becomes deepened in succeeding sutures. Already in the fourth suture the external lobe is divided by a small median saddle, which rapidly develops increasing prominence and depth ; after a diameter of about 3 mm., however, it merely becomes more complicated. The external saddle remains entire to a diameter of about 7 mm., when a notch appears on its external side, whilst the summit suggests tripartition. Further development leads to an increased emphasis on the lateral notch, which becomes a marked feature of the genus, and also in the three-fold character of the summit, the median lobule of which, however, becomes enlarged and divided. The first lateral lobe becomes complicated, at about the same diameter as the external saddle, by unequal division, the inner notch being

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[1] S. S. Buckman, " Jurassic Chronology—1 : Lias," *Q.J.G.S.*, vol. lxxiii, 1917, p. 288.

[2] J. W. Tutcher and A. E. Trueman, " The Liassic Rocks of the Radstock District," *Q.J.G.S.*, vol. lxxxi, 1925, p. 613.

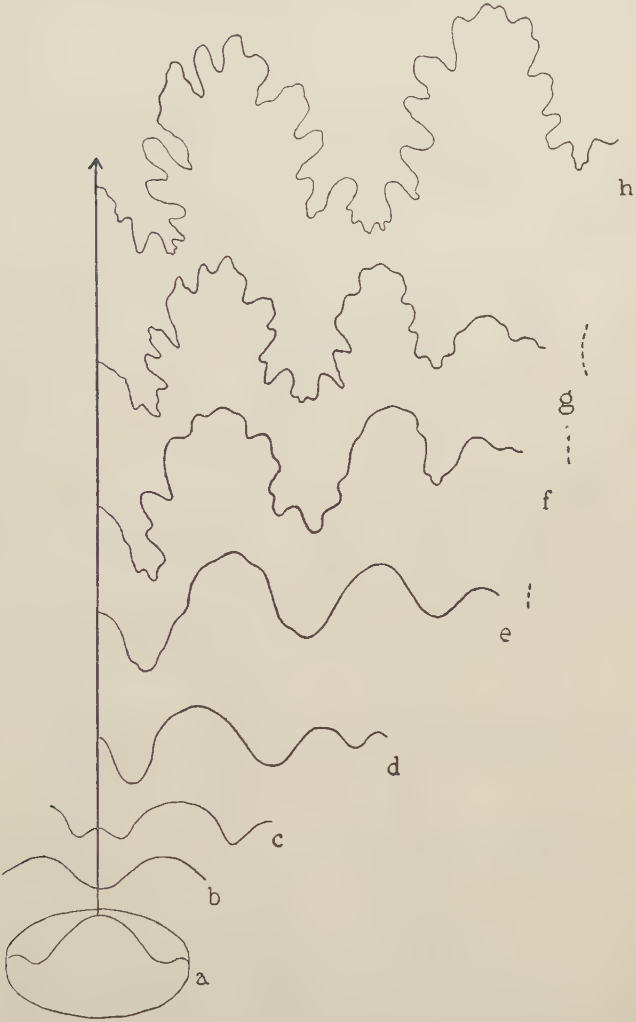

FIG. 1.—Sutural development in *Victoriceras victoris*. (*a*) Protoconch and first suture; (*b*) 2nd suture; (*c*) 4th suture; (*d*) at 3·3 mm. diameter; (*e*) at 7·5 mm. diameter; (*f*) at 15 mm. diameter; (*g*) at 27 mm. diameter; (*h*) at 41 mm. diameter. *a–b* × 40; *c* × 30; *d* × 20; *e* × 15; *f* × 8; *g–h* × 4·8.

the most prominent; it is rather more than half as deep as the external saddle. The first lateral saddle becomes feebly tripartite at about 8 mm. diameter. As usual, with growth, complication of the whole suture is introduced by minor frilling, and after a diameter of about 8 mm. the suture is noticeably inverse. Auxiliary lobes and saddles are introduced periodically after a diameter of about 3 mm.

Whorl Shape. (Figs. 2*a*–*f*.)

The protoconch (Fig. 2*a*) is the usual barrel-shaped structure, its width being 0·575 mm. The succeeding whorls are normal in their development from a stout depressed nepionic stage to the higher more compressed type characteristic of the adult. The relative increase in whorl height is marked, however, only in the first few whorls: after a diameter of about 5 mm. there is little change. As the coiling of the shell remains practically constant throughout growth, this slight percentage increase in whorl height is accompanied by a corresponding slight decrease in the percentage width of the umbilicus. The greatest change occurs, as usual, in the reduction of the relative whorl thickness; this proceeds rapidly in the first few whorls, but becomes much retarded after a diameter of about 12 mm. The depressed whorl shape (in which the thickness is greater than the height) persists to a diameter of about 5·5 mm. The umbilicus is thus fairly shallow in adult specimens, but the stout crescent-shaped nepionic whorls, which embrace those preceding to a very considerable extent, result in a corresponding deepened umbilicus at the centre.

Details of the changes with growth are as follows:—

Diameter in mm.	*Whorl height per cent.*	*Whorl thickness per cent.*	*Umbilicus per cent.*
1·0	—	90	—
2·3	43	74	21·5
3·5	45	60	—
5·3	49	52	22
8	52	40	20
11	52	32	*c.* 18
15	53	28	*c.* 19
23	53	27	18
30	53	26	17
40	52	26	16
244[1]	48	26	17

The evenly rounded venter of the earliest whorls commences to become angular at a diameter of about 3·5 mm., and at a diameter of 5 mm., the beginnings of a keel may be distinctly observed, but it has not been possible to determine where this becomes septicarinate.

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[1] Specimen figured in S. S. Buckman, *Type Ammonites*, vol. iii, 1919, pl. cxxxvi.

Ornamentation.

The whorls are smooth to a diameter of about 17 mm., whence with growth the ribs show an increasing prominence to a diameter of about 200 mm.—that is, the ornament is apparently anagenetic. The first ribs are sub-parallel; the auriculoid, which Buckman considered to be a specialized tubercle, does not appear to be present in the earlier stages, but is certainly distinct at a diameter of 24 mm. The umbilical terminations of the costae are always more prominent than the ventral, though less markedly so in the later stages. In larger specimens, the latest whorls show marked catagenesis of ornament leading to almost complete laevigation, the costae becoming not merely feebler, but also set further apart (as opposed to an earlier condensation): at various diameters, the number of costal elements per quarter-whorl is approximately as follows:—

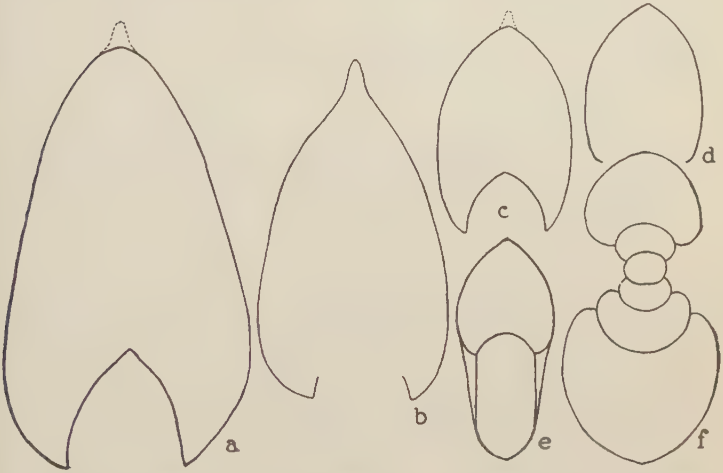

Fig. 2.—Changes in the whorl shape with growth in *Victoriceras victoris*. Whorl shape at (*a*) 30 mm. diameter; (*b*) 23 mm. diameter; (*c*) 15 mm. diameter; (*d*) 11 mm. diameter; (*e*) 8 mm. diameter; (*f*) 5·5 mm. diameter. *a–e* × 3·8; *f* × 7·6.

Diameter in mm.	*Along periphery.*	*Along umbilical border.*
30	10	6
45	15–17	11–12
180	32–36	15–16
250	6–3–(0)	6–3–(0)

(Disappearing in about ¼ whorl.)

At no stage is there any development of a corded keel.

III. The Development of Oxynoticeras oxynotum (Quenstedt).

The specimens examined were obtained by Mr. Linsdall Richardson [1] from spoil-heaps at the Gas Works, Gloucester.[2] They are apparently conspecific with Quenstedt's species and with the specimen figured by Buckman,[3] though there is some slight variation in the development of the sutures and of the ornamentation, both from the figures and amongst themselves. Almost certainly they are of Deiran (*oxynoti*) age.[4]

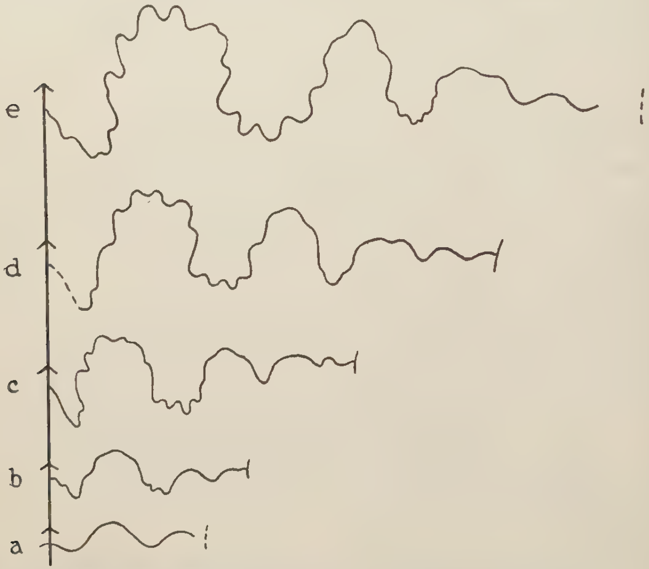

Fig. 3.—Sutural development in *Oxynoticeras oxynotum*. Suture at (*a*) 2·1 mm. diameter; (*b*) 5·3 mm. diameter; (*c*) 9 mm. diameter; (*d*) 14 mm. diameter; (*e*) 18 mm. diameter. *a* × 20; *b–e* × 10.

Sutural Characters. (*Figs. 3a–e.*)

The first sutures have not been seen. At a diameter of 2 mm. the external lobe is divided by a small median saddle which rapidly increases in prominence and depth, and which has already become frilled at a diameter of 5 mm. The external saddle remains entire to a diameter of about 4 mm., where the summit suggests tripartition ; the internal lobule of the summit becomes increasingly marked in succeeding sutures, being separated from the others by a prominent notch, and it is a characteristic of the species. In forms approaching *Oxynoticeras cultellus* (Quenstedt), however, the lobule is not so prominent, and as there is also much independent variation in the various other biocharacters, exact specific identification is sometimes very difficult. The first lateral lobe becomes frilled at a slightly earlier stage than the external saddle, but there is little change with growth apart from slight deepening of the elements; the lobe is almost as deep as the external saddle. The first lateral saddle becomes feebly tripartite at about 7 mm. diameter, and there is little complication with growth in the succeeding septa. The second lateral lobe is rather broad, and at about 12 mm. diameter is unequally divided in a characteristic fashion. Adventitious lobes and saddles are progressively added throughout growth, so that in large specimens there may be as many as six or eight of these adjuncts.

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[1] L. Richardson, "The Lias at the Gas Works, Gloucester," *Trans. Woolhope Nat. Field Club* (1914–17), 1918, p. 154.

[2] A. E. Trueman and D. M. Williams, "Notes on Some Lias Ammonites from the Cheltenham District," *Proc. Cotteswold Nat. Field Club*, vol. xxii, pt. 3, 1926, p. 251.

[3] S. S. Buckman, op. cit., 1919, pl. cxliii.

[4] S. S. Buckman, "Jurassic Chronology: I—Lias, Supplement I, West England Strata," *Q.J.G.S.*, vol. lxxvi, 1920, p. 62; S. S. Buckman, op. cit., 1917, p. 269.

Generally, the sutural development of *Oxynoticeras* is thus very similar to, but more rapidly effected than that of *Victoriceras*, though the latter is the more complicated in the later stages.

Whorl Shape. (Figs. 4*a*–*c*.)

The protoconch and first whorl(s) have not been seen. At a diameter of 1·7 mm. the whorl shape is stout, depressed, with a rounded profile—the characteristic nepionic stage of most Liassic ammonites. From this stage there is a rapid development, effected within a whorl, to the typical keeled oxycone form. This is accomplished by a proportionate reduction in whorl thickness, the depressed form being replaced by the compressed at a diameter of about 3·5 mm. This compression is enhanced to a diameter of 14–16 mm., after which there is little change. Throughout growth there is a slight but continuous increase in the degree of involution : that is, the proportionate umbilical width decreases while the proportionate whorl height increases.

Details are as follows :—

Diameter in mm.	*Whorl height per cent.*	*Whorl thickness per cent.*	*Umbilicus per cent.*
2·6	40	58	28
3·2	40	56	29
5·5	42	45	—
9	42	30	32
14	41	23	29
18	44	21	28
20	48	20	24
30	46	20	24
35	48	20	20
45	49	20	19
60[1]	50	20	19

[1] Specimen figured in S. S. Buckman, op. cit., 1919, pl. cxliii.

The first indications of an angular venter appear at a diameter of about 4 mm., whence the development of the carina proceeds in increasing angularity to a diameter of about 15 mm., after which there is little modification. The marked shoulder on the lateral flanks—a feature of the genus—is first clearly distinguished at a diameter of about 8 mm.

Comparing the changes in the whorl shape with those that occur in *Victoriceras*, it may be said that *Oxynoticeras* is more advanced in the earlier development of a compressed whorl shape and in the greater degree of whorl compression ultimately attained, but is more primitive in the lesser degree of involution (represented by a greater proportionate umbilical width, and less whorl height).

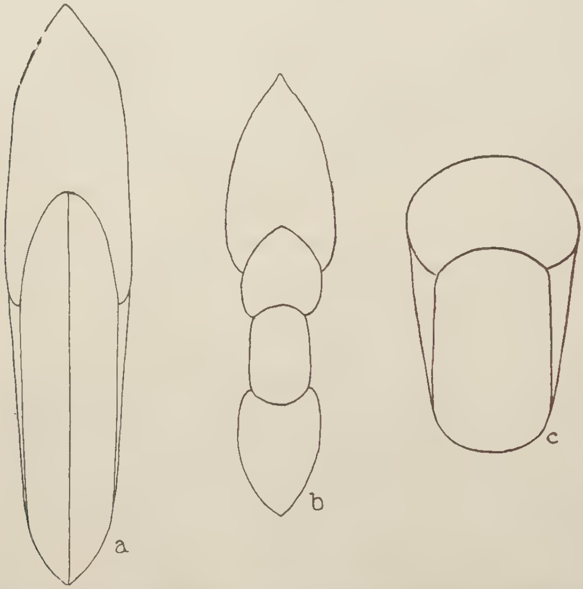

FIG. 4.—Changes in the whorl shape with growth in *Oxynoticeras oxynotum*. Whorl shape at (*a*) 18 mm. diameter; (*b*) 14 mm. diameter; (*c*) 2·6 mm. diameter. *a–b* × 4·3; *c* × 15.

Ornamentation. (Figs. 5*a–b*.)

The earliest whorls are smooth, but at a diameter of about 3·5 mm. faint costal elevations, rapidly increasing in prominence with growth, can be observed extending slightly obliquely forward from the umbilical margin. They completely traverse the shell at a diameter of about 6 mm., but throughout to the adult condition the ventral portions are never as prominent as those covering the umbilical slopes (which at their acme of development approach a nodose condition). The simple continuation of the umbilical costae across the shell is supplemented by the introduction of accessory elements along the ventro-lateral flanks; some of these approach typical auriculoids. The primary costae traverse the carina to give rise to a typical corded keel. This anagenesis of ornament proceeds to diameters varying in different individuals from such limits as 15 to 50 mm., but always this is followed by marked catagenesis, partial or almost complete, characterized, as in *Victoriceras*, both by a widening of the intercostal spaces and by a decreasing prominence of the costae; correspondingly, the crenulate keel becomes smooth.

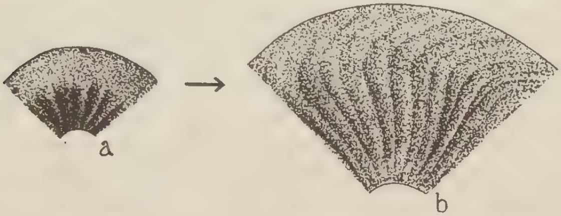

Fig. 5.—Development of the ornamentation in *Oxynoticeras oxynotum*. (*a*) Quarter-whorl at a diameter of about 4 mm. to show the relatively few coarse ribs which, with growth, increase in number per whorl, become much feebler, and traverse the flanks to the keel, swinging forward very markedly at the shoulder, as shown in (*b*) quarter-whorl at a diameter of about 20 mm. *a* × 5; *b* × 2·5.

IV. The Phylogeny of the Oxycones.

The most obvious feature in the ontogenies of the species now being considered is the direct development from the protoconch to the adult stages in the sutures, the degree of involution, and the gradual increasing compression of the whorl. In particular, apart from the ornamentation (which will be considered later), there is no evidence for descent from the more normal members of the Arietidae, as is indicated, for example, by the evolute crassicostate coronate inner whorls of the almost smooth compressed *Paracoroniceras*.

There are three possibilities concerning their ancestry:—

(i) The forms are cryptogenetic—their ancestors must be looked for outside the north-western European province. To assume this, however, merely shelves the question. For if such ancestors are ever found, the evidence for relationship must be of the same nature as would be adduced in the cases of (ii) and (iii) below, and the problem to be decided would be as between (ii) and (iii).

(ii) They are descended from more normal forms, such as evolute costate Arietidae, but evidence for this descent has been more or less completely lost in ontogeny by lipopalingenesis. This was the opinion of Buckman.

(iii) Their direct ontogeny indicates a correspondingly direct phylogeny, and they are descended from simple forms to be found in the underlying zones.

In a case in which the ontogeny is completely direct from the protoconch to the last whorl, there is no evidence intrinsic in the ontogeny on which it is possible to decide between (ii) and (iii); that is to say, there is no evidence in ontogeny of any deviation from a direct phylogenetic development. Only on other considerations, such as the discovery of a continuous series of transitional forms, would it be possible to determine the true relationships; these are not forthcoming in the forms now being considered.

The development of the ornamentation gives slight indications of a palingenetic deviation from the direct route to the adult laevigate condition both in *Victoriceras* and (more markedly) in *Oxynoticeras*. In ephebic and gerontic stages there is nearly always a marked catagenesis of the costae, while in the latter genus a brephic nodose stage is frequently present in the costal development along the umbilical border. From this nodose stage, the development varies in different individuals to a considerable extent, but in all cases there is a decrease in prominence of the nodes, accompanied by an extension, with dichotomy, of the costae over the ventro-lateral flanks. This deviation from the initial smooth stage through a nodose stage is much less marked in some specimens of *Oxynoticeras oxynotum* than in others, and occasionally it would appear that a direct ontogeny is almost completely attained in members of the species by a skipping of the crassicostate stage. It is clear that the last is not a coenogenetic character in the sense that it is a useful modification for a specialized mode of life in the young stages. The only other explanation appears to be that it is a recapitulation of a stage in phylogeny. It is of considerable significance that the ventro-lateral extensions of the costae in both genera are markedly deflected forward at the shoulder of the flanks (Fig. 5*b*), and it may be suggested that this shoulder is a relic of either a tricarinate or a carinate-bisulcate ancestral stage. As has previously been pointed out, this straightening to a direct ontogeny by a skipping of unnecessary stages results in "an ideal type of development, since it presumably implies the shortest period of immaturity".[1]

There is no coarsely-costate stage in the ontogeny of *Victoriceras*, and presumably it is completely skipped. It is interesting to note also that the arrival of the ornamentation in this form is delayed to a diameter usually considerably greater than that of *Oxynoticeras oxynotum*—a possible bradygenetic development.[1] Assuming this to be true, then, in the attainment of a completely laevigate condition (the usual concomitant of oxyconic development), *Victoriceras* is more advanced than *Oxynoticeras* in the later appearance of ornamentation, while the latter is the more advanced in its earlier loss.

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[1] A. E. Trueman and D. M. Williams, "Studies in Ammonites of the Family Echioceratidae," *Trans. Roy. Soc. Edin.*, vol. liii, pt. iii, 1925, p. 701.

The assumption of a descent of these oxycones from evolute costate Arietidae is in keeping with their stratigraphical position, and brings them into line with the development of oxycones in other families, such as, for example, the Angulitidae, the Harpoceratidae, and the Hoplitidae, in which descent from relatively loosely-coiled ornamented forms appears to be unquestioned. Nevertheless, an examination of the various biocharacters clearly demonstrates that *Victoriceras* and *Oxynoticeras* represent members of very different stocks, arriving at the oxycone condition along different routes.

In conclusion, I wish to thank Dr. A. E. Trueman for his interest in the paper and for many valuable suggestions.

Igneous and Associated Rocks from the Andes of Eastern Ecuador.

By George Sheppard, Ph.D.(Lond.), F.G.S., F.R.G.S., M.I.Min.E.

(PLATES XVIII–XX.)

Introduction.

THE suite of volcanic and metamorphic rocks described in this paper were collected by the writer in the early part of 1929. With the exception of the micaceous slate (Pl. XVIII, Fig. 3), which was found in situ along the valley of the Rio Patate near Guadaloupe, all the specimens were obtained near the Cascada de Agoyan, a locality a few miles downstream from Baños along the Rio Pastaza.

Previous contributions to our knowledge of the petrography of the rocks associated with this eastern section of the Ecuadorian Andes have been made by Sinclair,[2] Wasson and Sinclair,[3] and

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[1] Compare A. E. Trueman, "The Evolution of the Liparoceratidae," *Q.J.G.S.*, vol. lxxiv, 1919, p. 254, and "Aspects of Ontogeny in the Study of Ammonite Evolution," *Journ. Geol.*, vol. xxx, 1922, p. 140.

[2] Joseph H. Sinclair, "Geologia de la region oriental del Ecuador," *Anales de la Universidad Central, Quito*, Tomo xl, No. 264, 1928.

[3] T. Wasson and Joseph H. Sinclair, "Geological Explorations east of the Andes in Ecuador," *Bull. Amer. Assoc. Pet. Geol.*, vol. 11, No. 12, 1927.

Colony and Sinclair,[1] It is believed that the rock-types which form the subject of the present article are new in so far as the petrological descriptions are concerned, though their actual occurrences in the field has been commented upon in one of the papers cited.

General Notes on the District. (Fig. 1.)

One of the principal water-courses of this region is known as the Rio Chambo, and this river has eroded a deep, canyon-like valley through great thicknesses of lava and volcanic ash, especially in the vicinity of Licto and Calpi. As superficial rocks these comparatively recent geological formations are distributed over an extensive area, and they are well developed, with excellent sections, in the great interandine basin of Riobamba. The older formations, the schists and the gneisses, are rarely exposed beneath the newer

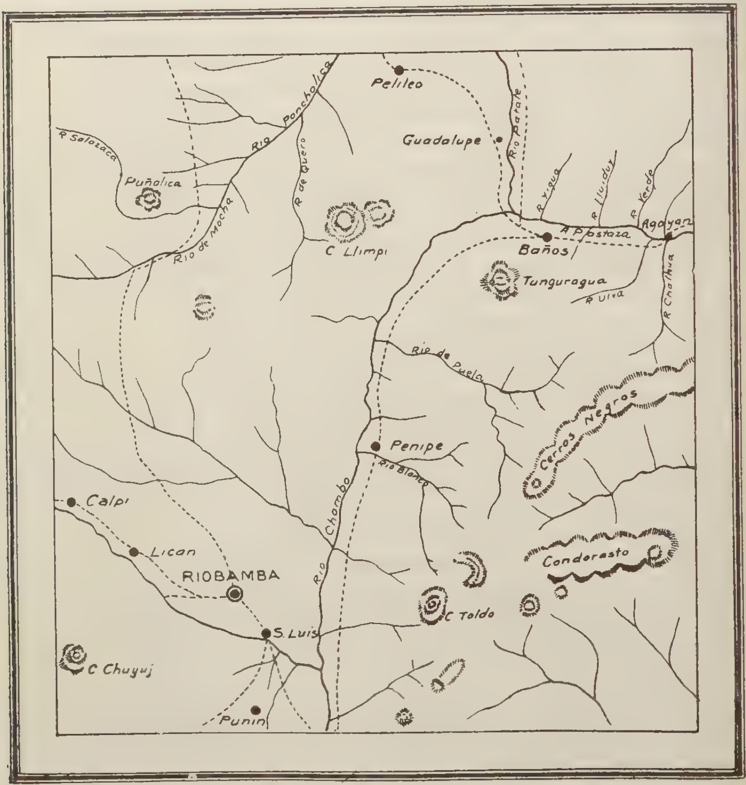

Fig. 1.—Sketch-map of District (1.445000). After T. Wolf.

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[1] R. J. Colony and Joseph H. Sinclair, "The Lavas of the Volcano Sumaco, E. Ecuador," *Amer. Journ. Sci.*, vol. xvi, 1928.

volcanics, although in many cases the larger river valleys have been eroded to a depth of several hundred feet.

The low rounded hills to the north of the villages mentioned above consist entirely of ash, pumice and associated lava streams. The latter are usually brecciated, particularly towards the base, a phenomenon which has no doubt, been caused by the flow-movement of the lava prior to its consolidation. The lava is normally in the form of an obsidian, yet it occasionally includes andesitic types which are invariably vesicular and are often scoriaceous. In few cases only are the vesicles, or flow-cavities, occupied by later products of mineralization. These volcanic rocks are of comparatively recent age, (Quaternary or Recent) and have been ejected, or have originated from, one of the neighbouring volcanoes, either Tunguragua or Altar.

From Riobamba northwards the road follows the valley of the Rio Chambo, this being deeply entrenched in the loosely-consolidated rocks, not infrequently attaining a depth of about a thousand feet. The majority of the exposed formations in this valley are volcanic in origin and have issued at different times from the active cone known as Tunguragua. Near Penipe, on the opposite side of the river, the higher slopes consist of andesitic and basaltic lavas, certain outcrops of which exhibit the columnar structure in a striking manner. Great masses of agglomerate and tuff, with occasional seams of sedimentary (i.e. inter-volcanic) sands are found intercalated throughout this confusion of rock types. Most of the lavas are horizontal, or of gentle declination, though local slipping has caused a fracturing of these formations towards the basal part of their outcrops. In places, the rock has weathered to a brick-red colour, and includes such varieties as andesite, pitchstone, and porphyritic basalt.

Near San Luis, to the south-east of Riobamba, the formations comprise alternating layers of volcanic dust with ejected blocks, silt, and seams of small rounded pebbles, the occurrence of the latter being unusual. A small stream course to the south of the village, in common with others of the same region, takes the form of a natural hanging-valley, with an incised section-fall of about 100 feet (Pl. XX, Fig. 1). This exposure consists of parallel and horizontal layers of volcanic debris, with occasional lenses of small, rounded pebbles.

On the road southwards towards Punin the volcanic terrain is superimposed by a series of cream-coloured, laminated silts which contain numbers of a small gastropod similar to the form of *Limnœa.* Rootlets of iron carbonate are also common in this marl. Upon this evidence it appears probable, therefore, that a number of shallow lakes occupied the natural depressions between the more prominent ranges before the present river system had eroded the deeper channel, and thus were responsible for the sedimentation of the marls. The same river has also formed a deep gorge through the formations near Punin, and the sedimentary deposits here exposed contain the remains of *Mastodon* and other animals, specimens of which were collected and described in 1883.[1]

These fossiliferous beds must be of Quaternary age, no doubt having originated as " wash " from the nearby elevations in the topography. The formations, however, are terrestrial in character, and are different in every way from the known Quaternary beds of the coast-belt (*tablazos*), though mammal remains similar to those from Punin have been found in the brea-pits of the Santa Elena Peninsula.

THE BAÑOS DISTRICT.

From Penipe, the trail follows the lower slopes of Tunguragua in a north-easterly direction, the geological formations consisting of volcanic ejectamenta, which occur in the nature of colossal screes arranged in a radial manner from the summit of the cone downwards. The rock accumulations are channelled at almost regular intervals by deep chasms, or *quebradas*, which have had the effect of exposing excellent sections in this loosely aggregated form of rock debris. (Pl. XX, Fig. 2). There is little doubt that these gorges were formed rapidly, and probably were simultaneous with the respective outbursts of volcanic activity, as they take their source practically at the summit of the crater itself and continue, with increasing dimension, as far as the lowlands beneath. Enormous boulder beds of great thickness and extent interstratify the different types of ash and lava, and huge fans of this material are found at the outlets of the *quebradas*, debouching far into the valley of the river which flows near the foot of the mountain. From Penipe to Baños the formations are of the order described in the foregoing, and as the most recent fans of ejected debris are not yet covered by vegetation, it can be assumed that they represent evidence of eruptions which have taken place during the last few years.

Near the town of Baños, however, the older slates, schists, and gneisses appear as a defined escarpment against which the newer lava flows have been arrested. The picturesque cascade known as the Falls of Agoyan, is found a few miles downstream, and this has been formed, in the first instance, by the presence of a lava flow (andesite) from Tunguragua which gravitated in a northerly direction over the softer micaceous schists, the latter rocks being highly contorted and in places vertical.

From Baños eastwards the northern bank of the river forms a high cliff or escarpment of slates and schists, and it is of interest to note that the columnar structure is well developed at the base of the lava flow (which occurs above the schists), i.e. at its contact with the underlying formations.

The deep and precipitous gorge, crossed by the bridge at the

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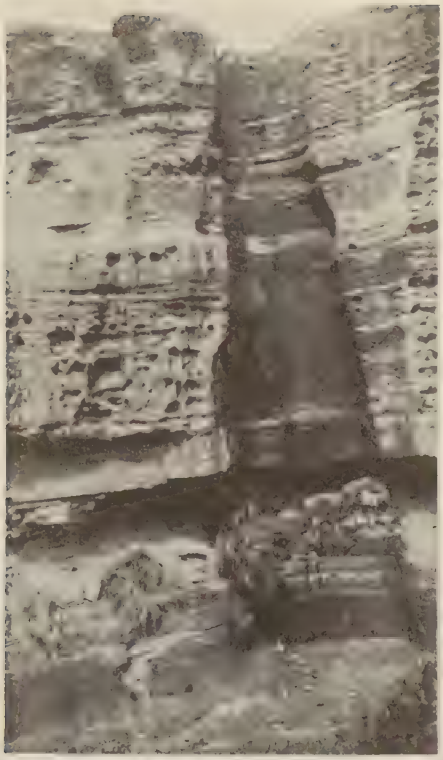
[1] Branco, W., *Una fauna de mamiferos fosiles de Punin, cerca de Riobamba en el Ecuador*, Berlin, 1883.



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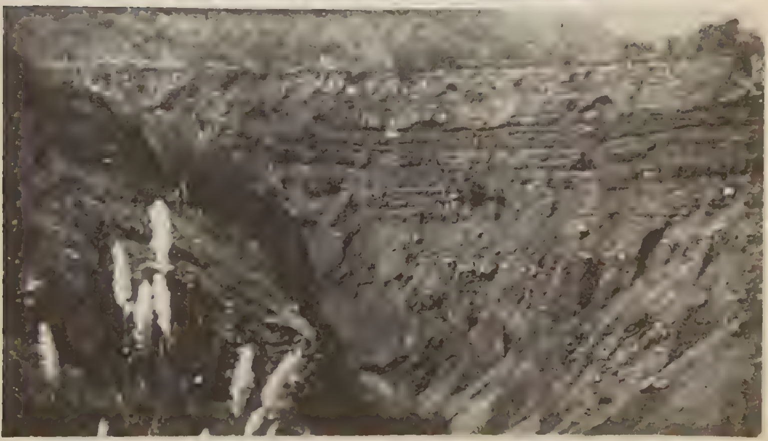

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FIG. 1.—"HANGING-VALLEY" IN VOLCANIC DEBRIS NEAR SAN LUIS, ECUADOR. Height of section, 100 feet.

FIG. 2.—GORGE THROUGH RECENT VOLCANIC AGGLOMERATE NEAR CERRO TUNGURAGUA, ECUADOR.

[To face p. 364.

town itself, was formed primarily by the breaking-off of the advancing front of the lava stream which moved in the direction of the schist escarpment. It is clear that before the time of this volcanic episode the Rio Pastaza took its course at the base of the schist. The lava then dammed the main river which, as a consequence, found a new channel by way of the crevice or rift produced by the separation of the frontal part of the lava from the main flow. It is quite obvious that this chasm, through which the Rio Pastaza flows at the present time, is far too precipitous and relatively narrow to have been caused by river action alone. (Fig. 2.)

Striking examples of hanging-valleys are also met with in this vicinity, notably at the confluence of the Rio Patate with the Rio Chambo. The flat, terrace-like effects in the topography of the river courses of this region have been caused by the presence of more or less horizontal ledges of volcanic rock, and it is reasonable to assume that before the first eruption of Tunguragua and the elevation of its cone, the schistose rocks formed an ancient land ridge which had a direction approximately east and west.

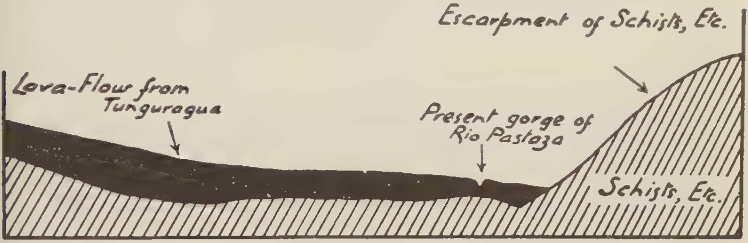

Escarpment of Schists, Etc.
Lava-Flow from Tunguragua
Present gorge of Rio Pastaza
Schists, Etc.

Fig. 2.—General Section near Baños, Ecuador.

The micaceous and garnetiferous schists, the petrological histories of which are discussed in the following pages, are found along the valley of the Rio Patate almost as far as Pelileo, and they thus include the greater part of the pre-volcanic series of the Tunguragua district. These older formations (probably of Palaeozoic age), strike to the north and indicate, in a general way, a steep easterly dip.

Petrographical Descriptions.

(1) The Recent Lavas.
(2) The Slates and Garnetiferous Schists.
(3) The Gneisses.

(1) The Recent Lavas.

Pl. XVIII, Fig. 1 (×12), *Pyroxene Andesite.*

This is a recent lava from Tunguragua and occurs as a flow superimposing the schists and gneisses at the Falls of Agoyan. In the hand specimen the rock appears as a compact, finely-crystalline, slate-grey lava, slightly vesicular (the vesicles indicating the "flow"), though these cavities are not filled in by secondary mineralization. Under the microscope, the groundmass is seen to be essentially porphyritic, consisting of a plexus of micro-crystalline laths of plagioclase, with a residual glassy base. Larger plagioclase phenocrysts occur in idiomorphic form, though many are twinned and occasionally exhibit a glomeroporphyritic habit. These felspar crystals are frequently decomposed along the direction parallel to the major axis. As a consequence, the felspars are glassy, or semi-vitreous, and present colourless sections under the microscope. The parallel twinning of albite, however, is quite distinct when viewed between crossed nicols. No hornblende is present, but the dominant ferro-magnesian mineral is a light greenish augite in small rounded crystals, the latter showing the characteristic cleavage of the mineral. Magnetite, also, occurs in small black crystals.

Pl. XVIII, Fig. 2 (×12), *Porphyritic Basalt.*

This specimen was collected from the slopes of Tunguragua in the vicinity of Baños, and probably represents part of an ejected block from the crater, It is Recent in age. Megascopically, the material is black in colour and vitreous in texture, and small white felspar crystals are recognizable on the weathered surface. Micro-cavities in parallel arrangement are common, and the general resinous appearance of the rock indicates its vitreous nature. Under the microscope the groundmass of this rock is of a crypto-crystalline nature and consists largely of minute laths of plagioclase with isotropic patches of melanocratic metostasis. Mica is typically absent, and the principal ferro-magnesian mineral is a light-green pyroxene which occurs in two generations, viz., the well-formed idiomorphic crystals, and also a granular form. Olivine, though fresh, is present as small phenocrysts, and not infrequently appears to have been crystallized in association with a greenish pyroxene (enstatite). The plagioclase felspars are porphyritic in habit, the larger phenocrysts being relatively fresh, and also are glomero-porphyritic in structure. Occasional examples of the larger plagioclase phenocrysts are surrounded by a dark grey "resorption" border, and in these cases the crystal contour of the mineral is not so sharply defined, being rounded or partly autopneumatolyzed by the magma. In other examples, the felspar crystal is seen to be crushed into a series of smaller prisms or granules, having entirely lost their original contour. Magnetite occurs throughout the groundmass in small opaque specks, and probably exists, as a comminuted form, in the vitreous portion of the rock. Although minute steam vesicles are seen in the hand specimen, no evidence of "flow" is observable under the microscope.

(2) SLATES AND GARNETIFEROUS SCHISTS.

Pl. XVIII, Fig. 3 (×12), *Micaceous Slate.*

This specimen was collected along the valley of the Rio Patate near the settlement of Guadaloupe. The rock itself forms part of the ancient escarpment referred to in the foregoing pages, and in the hand-specimen it appears as a typical phyllite, or micaceous slate, being foliated or rippled by partings or thin laminae of mica. The lack of fossil evidence, which if present in the original sedimentary rock has now been entirely obliterated by dynamic metamorphism, makes it impossible to approximate the geological age of these rocks. It is extremely probable, however, that the formations are Palaeozoic. Under the microscope it is at once apparent that the rock can be more correctly described as a microcrystalline schist. There is a marked parallelism or schistosity in the groundmass, due to alternating layers of a micro-mosaic of quartz (seen under polarized light) with finely divided lenses or streaks of carbonaceous or clay material. Mica is also present as an important constituent, occurring in very fine parallel laminae, though the individual fragments of this material are lath-shaped and ultra-microscopic in size. This mica is undoubtedly secondary in origin and is pale green or grey in colour. A characteristic feature of the groundmass also is the presence of small incipient " eyes " of granulated quartz which are elongated in the direction of the general foliation and exhibit strain-shadows between crossed nicols.

Pl. XVIII, Fig. 4 (×12), *Garnetiferous Mica Schist.*

This type is a more highly metamorphosed form of the phyllite described above under Fig. 3.

The hand specimen is a finely foliated, grey schist with microlaminae of silvery grey mica in which garnets occur, these latter minerals measuring an eighth of an inch in diameter. Under the microscope the groundmass is seen to consist of an extremely finely foliated plexus of mica, with granulated quartz, garnets and graphite. Subsidiary minerals such as chlorite and apatite are present and are of secondary origin, probably having been derived from the original constituents of the rock. The garnets are enclosed in " augen " fashion, and are occasionally surrounded by a lenticular space (elongated in the direction of the foliation), which is now occupied by calcite and quartz, the latter in mosaic aggregations. The micro-folia of this rock are locally contorted, though there is a general parallelism caused by the schistosity. Graphite, a mineral probably formed by the recrystallization of the carbonaceous element of the unaltered rock, is present in small brecciated groupings, and is associated with the mica of the groundmass. Garnets (pyrope) occur sporadically and form typical " augen ". They are usually surrounded by thin leaves of chlorite and mica.

Later products of serpentinization are also present in the vicinity of the " augen ". The chlorite is light green in colour and exhibits a fair basal cleavage after the habit of muscovite or lepidolite. Mica, of a secondary variety and occurring throughout the groundmass in a comminuted form, is finely foliated and shows high polarization tints under crossed nicols.

The mineral is probably of the form sericite or lepidolite. The quartz element of the rocks, which encloses well formed needles or rods of apatite, is granular in habit and exhibits a typical mosaic under polarized light. Strain-shadows are also seen in this mineral, these having been induced by the influences of dynamic metamorphism.

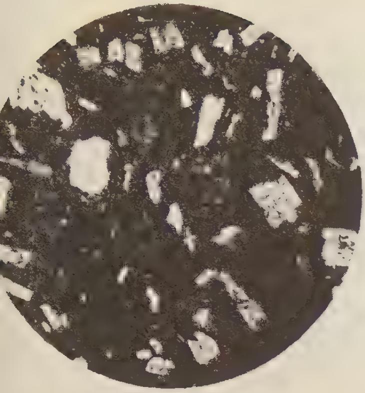
Pl. XVIII, Fig. 5 (×12), *Mica Schist.*

Under the microscope this type of schist shows evidence of considerable compression or distortion. The groundmass is minutely folded, the convolutions being clearly marked by the development of graphite and mica. The most important mineral in this rock is a dark-red garnet (probably a variety of pyrope) which never presents clear or fresh sections. On the contrary, it is always in a fractured condition, the fragments being associated with chlorite, mica and graphite. The quartz, though usually clear, exhibits pronounced strain-shadows under polarized light. It also occurs in a lenticular form and has a mosaic-like habit. Small needles of apatite are usually present in the quartz sections. Chlorite is present as a secondary mineral in the form of minute greenish laths and exhibit weak double refraction and a faint basal striation. The mica, which is an important constituent of the groundmass, is of the sericitic variety, being white or light-green in colour. The folia of graphite not infrequently pass through the lenticular groupings of quartz and thus appear to have been formed in a secondary manner as a direct result of the metamorphism to which the original rock was subjected.

Pl. XVIII, Fig. 6 (×12) (*between Crossed Nicols*).

Garnetiferous Mica Schist.—This is a coarser variety of schist than the specimens already described in the foregoing. In the hand-specimen it is a silvery grey schistose rock in which dark red garnets are conspicuous. Irregular lenses of quartz are also seen and the folia consist essentially of a white variety of mica. Under the microscope two varieties of mica are present, muscovite and sericite, the former being colourless in thin section whilst the latter has a distinct greenish tint. Both, however, occur in close association in the groundmass. The sericite usually forms a border to the garnets and the muscovite is typically interfoliated with the quartz, though the latter mineral is undoubtedly a later product of mineralization. The quartz, which occurs in " knots " or lenticles arranged parallel to the general foliation of the rock, is granular

PLATE XVIII.



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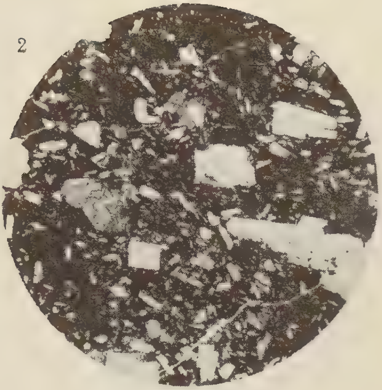

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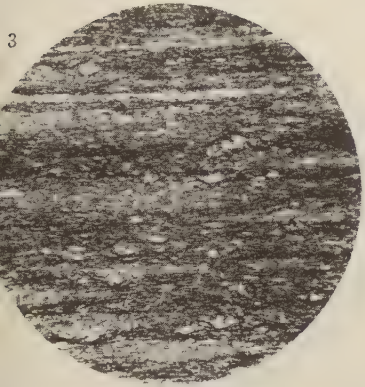

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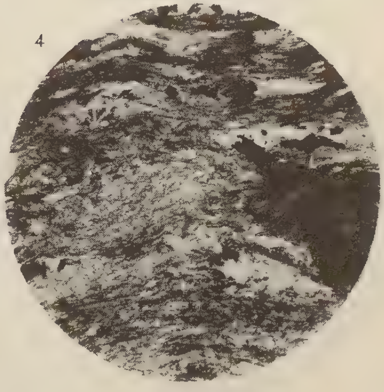

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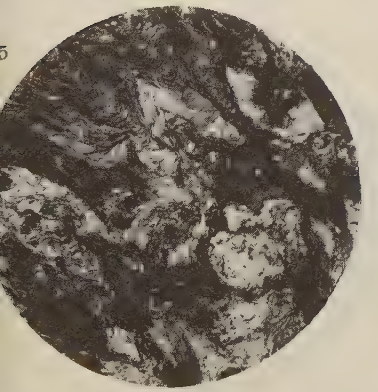

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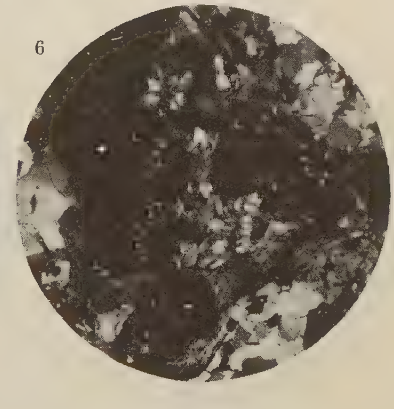

HOTOMICROGRAPHS OF ROCK SECTIONS FROM THE EASTERN ANDES OF ECUADOR.

[*To face p.* 368.

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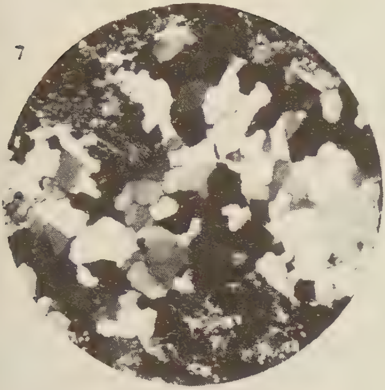

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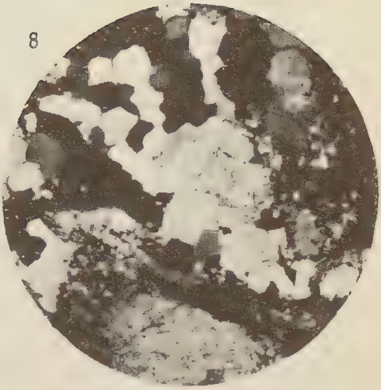

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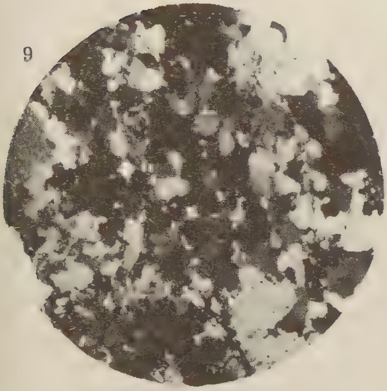

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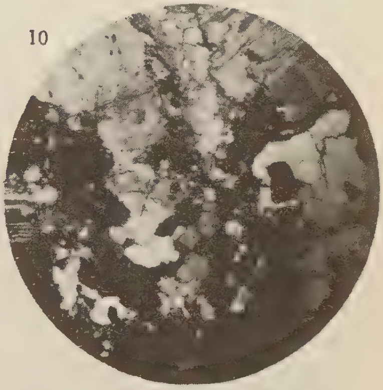

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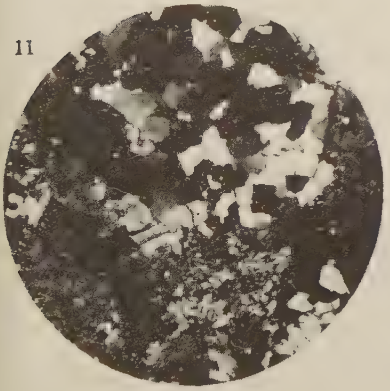

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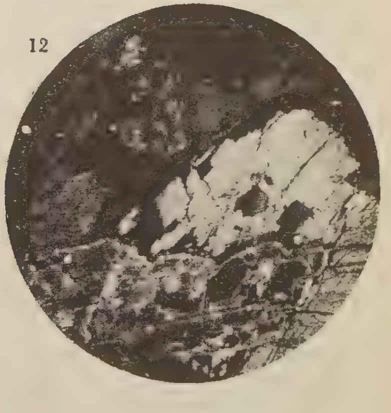

PHOTOMICROGRAPHS OF ROCK SECTIONS FROM THE EASTERN ANDES OF ECUADOR.

in habit and appears as an irregular mosaic under crossed nicols. Small rods or needles of apatite are included in the clear quartz.

The garnets, forming incipient "augen", are always fractured, the interstices or fracture-planes being filled in by a secondary form of clear quartz. The light pink colour of the garnet under the microscope indicates that it is probably pyrope. Specks of magnetite also occur sporadically throughout the groundmass and usually in association with minute flakes of chlorite.

(3) The Gneisses.

Pl. XIX, Fig. 7 (×12) (*between Crossed Nicols*).

Biotite Gneiss.—The gneisses are found in the same locality as the mica schists and hence must be considered as part of the same metamorphic complex. They probably represent, however, altered phases of a granitic massif which occurs in juxtaposition with the schistose rocks, and thus has been responsible, in a dynamometamorphic sense, for the types described in the previous notes.

As a general rule the gneissis rocks are leucocratic forms, being saccharoidal in texture and containing a high percentage of quartz and altered felspar. Under ordinary light the microsection is practically colourless and it is only between crossed nicols that the true characteristics of the rock are revealed. The quartz occurs as a coarse mosaic and occupies the greater part of the groundmass. It is normally clear though exhibiting strain-shadows between crossed nicols. Plagioclase felspar, and possibly microcline, are important minerals and, though the crystals are always shattered, it is still possible to recognize the multiple twinning. Biotite is common and occurs in sufficient quantity to be considered as an essential constituent of the rock. It is fresh and exhibits clear brown sections (with characteristic pleochroism), being present in small striated laths which are arranged in a parallel order. Muscovite also occurs, but as an accessory mineral. Enstatite is found in irregular phenocrysts, having a high refractive index and straight extinction with low double refraction. Graphite, in minute flakes or laminae, also occurs as a minor constituent in the groundmass.

Pl. XIX, Fig. 8 (×12) (*between Crossed Nicols*).

Granitic Gneiss.—Under the microscope both biotite and muscovite are seen in almost equal proportions. They have probably crystallized simultaneously, and have a tendency to be arranged in more or less parallel folia throughout the groundmass.

The biotite encloses granules of enstatite, and it is of interest to note that the folia of white mica follow the contours of the quartz element and thus are obviously of secondary origin. Quartz occurs as a clear mosaic (with minute inclusions), and exhibits strain shadows. Felspar (plagioclase), and possibly microcline, are found as important constituents, and though the twinning is recognizable it is evident from their shattered condition that the rock has been subject to intense tectonic strain or compression. The felspars are completely silicified and in several instances they appear under ordinary light as part of the quartz mosaic. Under crossed nicols, however, their plagioclastic nature is at once apparent and multiple twinning can be recognized. Hornblende occurs sparingly and in the one instance identified in this slide, the cleavage can be seen though the mineral itself has been altered into an indefinite grouping of chlorite, mica, serpentinous products and quartz.

Pl. XIX, Fig. 9 (×12) (*between Crossed Nicols*).

Gneissic Aplite.—In the hand specimen this rock has the appearance of a typical aplite, or acid vein, which is often associated with true granite masses. It is a white, saccharoidal rock in which light-coloured felspar can be observed in minute parallel laminae.

Under the microscope, the rock is practically colourless in ordinary light, the field being transparent. Between crossed nicols the greater part of the groundmass is seen to consist of a quartz-felspar mosaic, the quartz having been fused into an irregular mass of rounded fragments. The felspars (plagioclase) retain their original crystal contours, though a certain amount of shattering is also present. Flakes of chlorite and granules of enstatite are subsidiary minerals, whilst muscovite occurs in thin folia. Biotite is practically absent. Relatively large crystals of plagioclase felspar occur in the groundmass in association with the quartz mosaic.

Pl. XIX, Fig. 10 (×12) (*between Crossed Nicols*).

Foliated Gneiss.—This type is similar in many respects to the gneisses described in the foregoing, and is seen, under the microscope, to consist essentially of a fused matrix (or mosaic) of quartz and plagioclase. White mica, biotite and graphite occur in minor proportion as folia throughout the groundmass, and the clear quartz occasionally encloses needles or small rods of apatite.

Pl. XIX, Fig. 11 (×12) (*between Crossed Nicols*).

Gneiss.—This is similar to the type described under Fig. 10, the greater part of the groundmass consisting of a quartz-plagioclase complex. Subsidiary minerals include biotite and muscovite and enstatite. In this specimen the white and brown micas exhibit a tendency to simultaneous crystallization in small groups, these being sporadically arranged throughout the groundmass.

Pl. XIX, Fig. 12 (×12) (*under Crossed Nicols*).

Actinolite Schist (?).—This specimen occurs as a vein-like product in one of the garnetiferous schists near the Falls of Agoyan, and consists essentially of actinolite and calcite. The actinolite occurs in radiating groups of elongated, grass-green crystals or laths, which are in the form of rosettes, penetrating the calcareous matrix of the rock in a sporadic manner. Under the microscope the groundmass proper consists of calcite which exhibits very well-defined cleavage, with the usual high polarization tints under crossed nicols. The actinolite also shows its characteristic optical reactions. It seems clear that this type of rock represents an extreme phase of dynamic metamorphism, and it must be assumed that the calcite has been derived entirely at the expense of the original lime-felspars of the rock. In a similar way, the actinolite is of secondary origin, formed from the primary ferro-magnesian minerals of the groundmass. With the exception of fine flakes of graphite and a little white mica, no other minerals can be recognized in this slide. It is quite possible, therefore, that this type of rock is of rare occurrence and has not been described previously.

ACKNOWLEDGMENTS.

The sections and photomicrographs described in this article have been prepared by Messrs. Flatters and Garnett, of Manchester, to whom the author is gratefully indebted. Thanks are also expressed to Mr. J. Birch Rorer, of Riobamba, through whose kindness and assistance the expedition was made possible.

The Action of Colloids in Precipitating Fine-Grained Sediments.[1]

By PROFESSOR P. G. H. BOSWELL, University of Liverpool.

WITH certain well-known exceptions, ancient sandy and clayey sediments do little more than approach a condition of uniform grain-size. The so-called clays, silts and sands, and their consolidated equivalents, the mudstones, shales, silt-stones and sandstones, receive their appellation in most cases from the dominant grade present. Actually they consist of a mixture of particles, distributed over a considerable range of grain-size, in which the dominant grade, especially in the case of the finer deposits, often amounts to less than 50 per cent of the whole.

Among the exceptions (that is, deposits which are almost uniform in grain) may be mentioned many blown sands, some fine-grained ball-clays and pot-clays, and the finer bands of varve-clays. In the case of ball-clays and pot-clays, however, the apparent uniformity of grain-size may be illusory, these deposits consisting actually of very fine aggregated material, of which the individual particles vary in diameter.

Further, when unconsolidated samples of marine sediments of Mesozoic or later age, such as Oxford Clay, Kimmeridge Clay, Gault, and London Clay, are shaken up with sea-water at ordinary temperatures, we find that even through a fall of only four inches, or less, these sediments settle out roughly according to their grade-composition, and the material which collects at the bottom of the test-tube or other vessel is clearly differentiated according to size, sand occurring below, silt above, and clay at the top. Usually about four different bands, with indefinite boundaries, can be observed. A microscopic examination of the material throughout a column of sediment formed in this way is instructive, for it shows a gradual transition in the dominant grain-size.

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[1] Summary of paper read before Section C of the British Association at Cape Town, 1929.

Similarly, if fresh-water deposits such as those from Bovey Tracey (Oligocene), Petrockstow (Oligocene), the Haldon Hills (Eocene), Dorset (Eocene), or from existing rivers, are allowed to subside in tap-water or distilled water after being well shaken up, a similar banding is to be seen, provided that the sediment is not too fine.

Further, if a sandy clay of mixed grade is allowed to subside in fresh water at various temperatures, freedom from convection currents being ensured, it is found that differentiation during redeposition becomes more and more marked as the temperature falls. In the neighbourhood of 4°C, banding is well-marked and reminiscent of that of varve-deposits.

Observations such as the above are doubtless familiar to most geologists, but their implications do not appear to have been fully considered. Indeed, further experimental work induced by these observations indicates that many interesting problems await investigation. The notes which follow are only to be regarded as suggestive.

The determining factors in the rate of subsidence of the grains occurring in sedimentary rocks are:

(*a*) *Gravity.* The rate of fall is in accordance with Stokes's Law if the particles are between certain size-limits (about 0·3 mm. and about 0·02 mm.). Above the major limit a particle falls in accordance with other laws, such as that of eddying resistance, and below the minor limit it *may* (although the problem has not been fully investigated) behave in accordance with Ladenberg's or some other modification of Stokes's Law. When the particle is extremely small, that is, of colloidal dimensions, the difference in density between the particle and medium is small, and its surface-area relatively large, with the result that the fall becomes almost infinitesimally slow.

(*b*) *The influence of electrolytes*, such as the salts dissolved in the waters of the seas, rivers or lakes, by which the rate of fall of silt and clay particles is greatly increased. Without going into detail, it may be said that through the action of electrolytes the particles become less mutually repellant and collect into flocks. These behave like larger particles and fall more rapidly than the individual constituent grains.

(*c*) The operation of the phenomenon which has recently been termed *co-precipitation* by Professor E. C. C. Baly, F.R.S., of the

University of Liverpool.[1] The phenomenon of mutual precipitation of colloids has long been known to physical chemists (see, for example, W. C. McC. Lewis, *A System of Physical Chemistry*, Vol. I, pp. 334–5, 1923) and indeed to geologists and soil-investigators,[2] if we are to judge from casual references to its effects. For example, it is well-known that finely-divided silica, calcium carbonate and clays of all types,[3] carry an electro-negative charge with respect to the water in which they are suspended. Colloids such as ferric hydroxide, aluminium hydroxide and extracts from plant and animal tissues carry an electro-positive charge under the usual laboratory conditions. The character of the charge can be proved by the direction of movement of the colloid or other matter when in suspension in the cataphoresis apparatus.

Of the chief electro-positive colloids occurring in nature, the so-called humic acids and the products of decayed animal tissue are most important among the organic, and ferric hydroxide foremost among the inorganic substances.

The humic acids and the colloids derived from decaying organisms consist of compounds of extremely complicated structure, and although it has been shown qualitatively that the substances act as precipitants of finely-divided clayey matter, etc., the quantitative estimation of the colloid required to precipitate a given quantity of suspensate [4] presents a problem of considerable difficulty. In the case of ferric hydroxide, however, the quantitative estimation of the amount so required is quite simple. The following experiments have been carried out to determine (*a*) the precipitative power of organic and inorganic colloids, and (*b*) the minimum concentration of colloid required to produce flocculation and precipitation of the suspensate. In the experiments mentioned below, the suspensates used were various clays of different origin—marine, estuarine, glacial and fluviatile—fuller's earth, finely-precipitated calcium carbonate, drewite, finely-ground quartz, and gelatinous silica. Experiments were also carried out with solutions of calcium bicarbonate and calcium sulphate.

The suspensate was shaken up for some time and then the colloid added, the rate of subsidence being noted; a separate quantity of the suspensate in water alone was always prepared as a control for comparative purposes. The rate of subsidence is affected by variation in temperature, and by vibration; hence the observed rate of fall is comparative rather than absolute.

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[1] Professor Baly has accumulated much interesting experimental information which it is hoped will become available to geologists before long.

[2] See, for example, G. H. Cox, R. S. Dean, and V. H. Gottschalk, *Bull. School of Mines and Met., Missouri,* Nov., 1916, p. 7; C. W. Correns, "Die petrographisch wichtigen Methoden der Kolloidchemie," *Fortschr. Min. Krist. Petr.*, vol. x, p. 139, 1925, and references therein cited; also E. Sampson, *Journ. Geol.*, vol. xxvi, 1923, p. 598.

[3] Except perhaps "acid" fuller's earth, which has been said to be electro-positive, although my own experiments with ordinary fuller's earth give a contrary result.

[4] "Suspensate," a term due to Professor F. G. Donnan, F.R.S., is used to indicate the inorganic material, sand, silt, clay, etc., which is in suspension. The term "suspensoid" is pre-occupied.

If, then, a few drops of dilute ferric oxide hydrosol (the dialysed iron of the pharmacists) be added to a suspension of clay, the particles segregate into flocks as a result of mutual reduction of their electric charges. The time taken for flocculation varies with the concentration, but is usually a matter of a few minutes at most. The large flocks then settle at a relatively rapid rate, the process being much quicker than sedimentation under the influence of electrolytes. Coarse particles like fine sand and coarse silt, which may have been slowly falling, are caught in the flocks, with a resulting increase of velocity. The sediments thus produced are found on microscopic examination to be similar to those of most fine-grained geological deposits, that is, they consist of fine clayey material throughout which grains of silt and sand are scattered.

If, instead of ferric oxide hydrosol, colloidal solutions from peat, sewage liquor, or extracts from putrifying animal matter are used, similar results are observed, the rapidity of fall being dependent on the concentrations. In the course of other investigations, Professor E. C. C. Baly has shown how potent is the action of sewage colloids in precipitating silts, clays and many fine-grained chemical compounds.

A comparison of the concentrations used in the experimental work with those occurring under natural conditions is made later (p. 380). The amount of suspensate used in all the experiments was 1 gm. (dried at 105° C),[1] and this was shaken up with 400 cc. of water in each case. The solution of dialysed iron contained ·0018 gm. of iron per cc., hence 1 cc. added to the 400 cc. of water gave a concentration of 4·5 parts of iron per million. The total depth of the water-column was 8 inches. As the complete tables of observations would occupy much space, a selection only of the results is given here.

1. *Sedimentation in sea-water at* 18° *C.*

Fall measured from surface of suspensate.

Concentration of ferric hydroxide 4·5 *parts iron per million.*

(*a*) *Kimmeridge Clay, Kimmeridge.*

Time 5½ hours.	Mixture fell	8 in.
	Control ,,	5 in.

(*b*) *Fuller's Earth, Somerset.*

Time 1½ hours.	Mixture fell	2 in.
	Control ,,	1 in.
Time 2 hours.	Mixture ,,	8 in.
	Control ,,	3 in.
Time 3 hours.	Control ,,	8 in.

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[1] In the case of the gelatinous silica, 1 gm. contained ·38 gm. of silica dried at 105° C.

(*c*) *Colloidal Silica.*

Time 1½ hours.	Mixture fell 8 in.
	Control ,, 3 in.
Time 4 hours.	Control ,, 8 in.

2. *As* 1 *above*, but fall measured by reading print through water-column.

(*a*) *Kimmeridge Clay.*

Time 5 hours.	Mixture fell 8 in.
	Control ,, 5 in.
Time 6 hours.	Control ,, 8 in.

(*b*) *Petrockstow Clay.*

Time 6½ hours.	Mixture fell 8 in.
	Control ,, 5 in.
Time 8 hours.	Control ,, 8 in.

(*c*) *Fuller's Earth.*

Time 2 hours.	Mixture fell 8 in.
	Control ,, 4 in.
Time 3 hours.	Control ,, 8 in.

(*d*) *Precipitated Chalk.*

Time 5 hours.	Mixture fell 8 in.
	Control ,, 5 in.
Time 6½ hours.	Control ,, 8 in.

(*e*) *Colloidal Silica.*

Time ½ hour.	Mixture fell 3 in.
	Control ,, 1 in.
Time 1½ hours.	Mixture ,, 8 in.
	Control ,, 2 in.
Time 4 hours.	Control ,, 8 in.

3. *Sea-water at* 18° *C. Iron* 9 *parts per million.*

(*a*) *Kimmeridge Clay.*

Time 4 hours.	Mixture fell 8 in.
	Control ,, 4 in.
Time 6 hours.	Control ,, 8 in.

(*b*) *Fuller's Earth.*

Time 1¼ hours.	Mixture fell 5 in.
	Control ,, 2 in.
Time 1¾ hours.	Mixture ,, 8 in.
Time 3 hours.	Control ,, 8 in.

(*c*) *Precipitated Chalk.*

Rates of fall as for 4·5 parts iron per million.

(*d*) *Colloidal Silica.*

Time 1 hour.	Mixture fell 8 in.
	Control ,, 1½ in.
Time 4 hours.	Control ,, 8 in.

In general, therefore, the rate of fall is increased by increasing the concentration of iron.

4. *Sea-water at* 18° *C. Iron* 13·5 *parts per million.*

(*a*) *Kimmeridge Clay.*

Time 3½ hours.	Mixture fell 8 in.
	Control ,, 3 in.
Time 6 hours.	Control ,, 8 in.

(b) Fuller's Earth.

Time 1 hour.	Mixture fell 8 in.
	Control ,, 1 in.
Time 3 hours.	Control ,, 8 in.

(c) Colloidal Silica.

Time ½ hour.	Mixture fell 8 in.
	Control ,, 1 in.
Time 4 hours.	Control ,, 8 in.

Greater concentration of iron, therefore, further increased the rate of fall.

5. *Sea-water at* 25° *C. Iron* 13·5 *parts per million.*

(a) Kimmeridge Clay.

Time 25 min.	Mixture fell 2 in.
	Control ,, ¼ in.
Time 45 min.	Mixture ,, 8 in.
	Control ,, ¾ in.

(b) Fuller's Earth.

Time 25 min.	Mixture fell 5 in.
	Control ,, ½ in.
Time 30 min.	Mixture ,, 8 in.
	Control ,, 1½ in.

(c) Precipitated Chalk.

Time 3 hours.	Mixture fell 8 in.
	Control ,, 5 in.

(d) Colloidal Silica.

Time 20 min.	Mixture fell 8 in.
	Control ,, 4 in.

In each case flocculation was more pronounced than at 18° C, although in the case of colloidal silica some flocks remained in suspension. As would be expected from the marked reduction in the viscosity of the water at 25° C (a temperature which approaches but does not equal that of tropical seas) the rates of fall were appreciably increased.

The results of repeating these experiments in *tap-water* were similar to those in sea-water, but the rates of fall were on the whole slower. It may be noted that fine residual suspensions of a clay in tap-water, after standing for a week, are completely precipitated by ferric hydroxide in a few hours.

These experiments were also carried out in distilled water in order to determine whether the presence of electrolytes in sea-water and tap-water was essential to the phenomenon of co-precipitation. Such experiments became the more necessary since recent work by Moore and Maynard[1] shows that ferric hydroxide is precipitated in a few days when solutions of colloidal iron and silica, stabilized by organic matter, come into contact with electrolytes, but that the silica is only completely coagulated after several months.

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[1] *Econ. Geol.*, vol. xxiv, p. 285, 1929. My experimental work was carried out and this paper prepared before the appearance of Messrs. Moore and Maynard's most valuable contribution.

6. *Distilled Water at* 18° *C. Iron* 4·5 *parts per million.*

(*a*) *Kimmeridge Clay.*

Time 4½ hours.	Mixture fell	2 in.
	Control ,,	¾ in.
Time 6½ hours.	Mixture ,,	5 in.
	Control ,,	1 in.
Time 24 hours.	Control ,,	3 in.

(*b*) *Petrockstow Clay.*

Time 24 hours.	Mixture fell	1 in.
	Control ,,	½ in.

(*c*) *Fuller's Earth.*

Time 1¼ hours.	Mixture fell	8 in.
	Control ,,	1 in.

(*d*) *Precipitated Chalk.*

Time 2¼ hours.	Mixture fell	5 in.
	Control ,,	3 in.

(*e*) *Colloidal Silica.*

Time 1¼ hours.	Mixture fell	8 in.
	Control ,,	2 in.

7. *Distilled Water at* 18° *C. Iron* 13·5 *parts per million.*

(*a*) *Kimmeridge Clay.*

Time 4 hours.	Mixture fell	8 in.
	Control ,,	½ in.

(*b*) *Fuller's Earth.*

Time ½ hour.	Mixture fell	8 in.
	Control ,,	¼ in.

(*c*) *Precipitated Chalk.*

Time 3 hours.	Mixture fell	8 in.
	Control ,,	5 in.

(*d*) *Colloidal Silica.*

Time 1 hour.	Mixture fell	8 in.
	Control ,,	1 in.

A comparison of these results with those in experiments 1 and 2 above shows that the absence of electrolytes does not appear to reduce the co-precipitating effect; indeed, co-precipitation would appear frequently to be more effective in the absence of electrolytes.

Similar effects were obtained by the use of both peat extracts and animal extracts, although the action of the former was slower and in some cases anomalous, probably as a result of the weaker concentrations. Perhaps the most startling results were those seen when a colloidal animal extract was added to a sediment of mixed grade such as London Clay. Most of the suspensate was brought down in a few minutes, and the suspension cleared entirely in a few more. The figures obtained are not set out at length in this paper, largely because it is desirable that some means should be found of expressing the quantity of precipitable electro-positive organic colloid in use in the experiments. Also, it now appears essential that the experimental work should be repeated and accompanied by determinations of the hydrogen-ion concentration in each case.

An interesting point, though a side issue to the general problem outlined above, is the fact that bacteria are known to carry an electro-negative charge. They can therefore be, and have been, co-precipitated with an electro-positive colloid such as ferric hydroxide. The possible bearing of this on the precipitation of lake or bog iron-ores through the agency of bacteria will be obvious to the reader.

From the point of view of grain-size, it is worthy of note that Professor Baly found with his suspensions (and I observed the same effects with London Clay) that the silt-grade, especially material of diameter from ·06 to ·02 mm., is more rapidly and easily co-precipitated than true clay. The latter requires a relatively larger quantity of electro-positive colloid to increase its rate of sedimentation.

The possible geological bearing of this experimental work may now be considered.

When the velocity of currents bearing sand, silt and clay in suspension is so far reduced as to permit gravity, aided by the flocculating action of electrolytes, to cause sedimentation the first material deposited will be sand with the silt and flocculated clay which has had but a short distance to fall. The material deposited later will consist of silt and flocculated clay from higher levels in the water, the flocks of clay having trapped sand and silt during flocculation and subsidence. With this silt and clay will fall more free sand only so long as fresh supplies of material are brought in by the currents. Thus the sediment which accumulates on the sea-floor will be of mixed grade so long as there is a continuous supply of fresh material. As soon as the supply of suspensate ceases, that which is already in the water settles out in accordance with the action of gravity and of electrolytes, and becomes differentiated in the process. According to its mechanical composition, the resulting deposit may show rough banding or may consist of material which is coarse and sandy at the base and becomes gradually finer above until it ends as pure clay. A fresh influx of suspensate of mixed grade will cause the clay to be covered by sandy material, the junction being sharply defined. This would seem to explain the formation of deposits like those not infrequently found in the Pre-Cambrian and Lower Palaeozoic rocks, which consist of beds having a vertical transition in grain-size. These deposits are an expression of rhythm or periodicity in deposition and they differ from varve-deposits only in their less complete differentiation of the grades.[1]

It is extremely doubtful whether electro-positive colloids have any effect on sedimentation (except perhaps locally) in the open sea, because of their very great dilution. It may be noted, however, that in estuaries into which drainage from large towns is delivered, electro-positive colloids may play an active rôle in accelerating the deposition of mud and silt.

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[1] This manuscript was in the Editor's hands before the appearance of Prof. E. B. Bailey's notes on "graded bedding" in the GEOLOGICAL MAGAZINE of February, 1930. It seems to me that Prof. Bailey over-estimates the difficulties of explaining the formation of graded bedding.

In the case of fresh-water basins such as lakes, river back-waters and marshy pools, the flocculating action of the electrolytes in the water is much weaker than in sea-water. In the first place it is clear that slowest fall and most perfect differentiation into grades is to be seen where gravity operates on the suspensate unaided by electrolytes or electro-positive colloids and where the temperature of the water is near freezing-point. Thus the coldness of glacier-waters, combined with their purity (for there is an almost entire elimination of chemical weathering), would appear to be the cause of varve-banding.

In ordinary lake-clays, such as those of the Eocene or Oligocene, laid down presumably under sub-tropical or at least warm-temperate conditions, we might reasonably expect a certain amount of mechanical differentiation of the constituent silt and clay. However, rhythmic banding in such deposits is relatively rare. On the contrary, so far as observations are available, they are usually "homogenous" throughout, and consist of an intimate mixture of material of different sizes. A continuous supply of sediment in shallow basins might of course result in such a mixture, but it is questionable whether the relatively small quantity of electrolytes in fresh-water is wholly responsible for the precipitation. Frequently, however, we find in fresh-water deposits evidence of plant life, such as beds of lignite and remains of crustacea, mollusca, etc. Diatoms and algae also are frequently present. Even in apparently unfossiliferous clays, like those of Petrockstow or Wareham, we often find organic matter finely distributed throughout their mass. In some cases it is invisible, but is revealed in complete chemical analyses. Here it may be noted that we have relatively little quantitative information regarding the organic constituents of common sediments. It has usually been regarded as sufficient to record a "loss on ignition", or "loss above 105° C" with no indication as to what proportion of this loss is due to combined water and what to oxidation of organic matter. In some cases even loss of carbon dioxide from carbonates may be included. A recently published Memoir of the Geological Survey (Special Reports on Mineral Resources, vol. xxi, Ball Clays) contains, it is true, seven analyses of Bovey Clays and three of Petrockstow Clays in which the carbonaceous matter has been determined, but these are exceptional examples. The figures vary from ·01 per cent to 3·25 per cent, and may represent a considerable amount of original colloidal organic matter. On the other hand it may be lignitic material; without examination of the specimens, it is not possible to say.

The deposit of finely-divided calcium carbonate ("drewite") found off the shores of Florida, the Bahamas, etc., and attributed to bacterial action, contains a notable quantity of organic colloids intimately mixed with it. Professor R. M. Field tells me that investigations are now proceeding to determine the composition of the distillates obtained from it. Also, in describing the so-called "pipe-clays" (which are actually deposits of calcium carbonate) of the South Australian lagoons, Sir Douglas Mawson drew attention to the quantity of decomposing algal matter present in many of the basins.[1]

In an account of the varve-deposits of the Eocene in Colorado, Utah, and Wyoming,[2] W. H. Bradley mentions pairs of laminae, one of which is richer in organic matter than the other. As his paper is published only in abstract, we await further details with interest.

In partially or completely enclosed bodies of water, like river back-waters, marsh pools, lakes, and lagoons, it is conceivable, to put it no higher, that electro-positive colloids may play an active part in precipitating fine-grained sediment at such a rate that even where the supply is not continuous and the depth of water not small the sediment remains undifferentiated into grades. In the experiments referred to above, the concentrations of colloids and suspensate were comparable with those of many rivers of to-day.[3] Moore and Maynard [4] analysed samples of North American lake- and river-waters and obtained figures for ferric hydroxide varying from 1·3 to 14·4 parts per million, although the average for North America was less than 1 part per million. Many rivers in other parts of the world carry 3 to 6 parts per million. Thus the concentration is often of the same order as in the experiments here undertaken. The quantity of organic matter in the water of the River Amazon is stated to be 5·7 to 8·9 parts per million, but exactly what is meant by this statement and how the organic matter was determined is not clear; it is therefore difficult at the present time to institute comparisons with the experimental results summarized above. As regards the concentration of suspensates, numerous rivers carry far more than 2,500 parts per million by weight, which was the concentration used in the experimental work. The sedimentation effects can, of course, be obtained experimentally with a much smaller quantity, but in very small concentrations ferric hydroxide acts in certain cases rather as a stabilizer.

The recent work of Moore and Maynard [5] includes a wealth of experimental results which bear closely on the chemical precipitation of iron and silica. The work was undertaken with the object of throwing light on the formation of banded iron ores and jaspilites. In addition to the *chemical* action, however, it seems possible that *physical* action such as co-précipitation may play a part in the production of these rocks. Further work is necessary before the effectiveness of co-precipitation can be established with certainty. Some cherts and flints may be formed by deposits of silica co-precipitated on the sea-floor with organic matter, the latter being represented at the present time by the carbonaceous matter which is often disseminated throughout these rocks.[1]

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[1] *Quart. Journ. Geol. Soc.*, vol. lxxxv, p. 620, 1929.

[2] *Bull. Geol. Soc. Amer.*, vol. xl, p. 133, 1929 (abstract). Since published as *U. S. G. S.* Prof. Paper No. 158 E.

[3] Except in the case of gelatinous silica.

[4] Op cit., p. 274.

[5] Op. cit., pp. 272–303, 365–402, and 506–27. On p. 512 the authors touch on the problem of co-precipitation.

In conclusion, I have to thank Mr. T. Eden, B.Sc., for much assistance in the experimental work referred to in this paper.

REVIEWS.

The Pre-Quaternary Sedimentary Rocks of Sweden, III. The Paleozoic and Mesozoic Sandstones of Sweden. By Assar Hadding. *Meddel. Lunds Geol.-Miner. Inst.*, No. 41, 1929, pp. 1–287.

About two years ago, Dr. Assar Hadding published the two earlier parts of his treatise on the sedimentary rocks of Sweden (reviewed in the Geological Magazine, 1928, p. 93). The first of these was a general conspectus; the second a description of the Palaeozoic and Mesozoic conglomerates. We now welcome the large and well-illustrated volume which forms Part III of the series. Except for the accounts of tracks and impressions such as those of *Medusina, Cruziana, Scolithes*, etc., the fossil-contents of the sandstones are not specifically dealt with; nor are the accessory detrital minerals, partly because, as the author says, the treatise is but a summary, and partly because "these minerals are never so abundantly or so constantly present that they may be said to be characteristic of the one or the other rock". In the absence of detailed evidence, we accept the latter statement with reservations. The various rocks are described with the idea of illuminating more particularly the characters and conditions of formation of the sediments. The author first makes a general survey of the sandstones and includes a discussion of the form and size of the grains, the cement, colour, mode of occurrence and preservation of the fossils, and characters such as lamination, ripple-marks, rain-impressions, etc. This is followed by chapters on the diagenesis and metamorphism of the rocks. The remaining three-fourths of the book are occupied with a full account of the sandstones of the Cambrian (including the sparagmites), Ordovician, Silurian, Keuper, Rhaetic-Lias and Cretaceous. Finally, the author discusses classifications and decides in favour of a genetic grouping. He adds interesting and suggestive notes on the characteristic petrological features of "transgression sandstones", "oscillation sandstones" and "regression sandstones", in which the references to the formation of glauconite and phosphorite, as well as the enrichment of sediments in those minerals, will especially interest British readers. We may be grateful to Dr. Hadding for the information he has collected and the immense amount of work he has undertaken in writing this volume, and may look forward with pleasurable anticipation to further publications on the fine-grained sedimentary rocks of Sweden.

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[1] H. C. Sargent, Geol. Mag., Vol. LXVI, 1929, pp. 399–413.

GREENLAND: ITS NATURE, INHABITANTS AND HISTORY. By TH. N. KRABBE. Pp. xvi + 130, 170 plates, index and map. Copenhagen: Levin and Munksgaard; London: Humphrey Milford. 1930. Paper, 33*s.*; cloth, 40*s.*

THIS book is not in the strict sense geological, and is concerned rather more with the history and the inhabitants of Greenland than with the natural history; there is much, however, that is of value to geologists and physiographers. A feature is the large number of full-page photographs, all of them of merit and interest. The actual amount of letterpress devoted to geology is small, but this is more than counterbalanced by the wealth of illustrations, which do full justice to the beauty and character of Greenland scenery.

J. M. W.

CORRESPONDENCE.

LATERITE.

SIR,—In the January, 1930, number of the GEOLOGICAL MAGAZINE you kindly reprinted an article on laterite that I wrote originally for the Agricultural and Forest Departments of the Straits Settlements and Federated Malay States after the Fourth Pacific Science Congress. Since the article appeared correspondence has passed that prompts me to add to what I then wrote, primarily with a view to emphasizing the agreement between three Directors of Geological Surveys in tropical countries on the subject of tropical weathering.

It may be remembered that in 1909 (GEOL. MAG., p. 431) I objected to a proposition put forward by a reviewer in the *Bulletin* of the Imperial Institute that only products of weathering containing free aluminium hydroxide in hot, moist climates should be considered as laterite. Since then many geologists have agreed to designate by the term "lateritization" or "laterization" the formation of aluminium hydrate as a product of weathering as distinguished from the formation of hydrated silicate of aluminium. The former is thought to be typical of tropical climates, the latter of temperate climates. Others include ferric hydrate as a product of lateritization, and I have learned recently that some hold that ferric hydrate alone is enough to justify the term.

In three tropical countries, however, Indo-China, which is all south of the Tropic of Cancer ; the Netherlands Indies, which lie on either side of the Equator ; and Malaya, close to the Equator and lying between Indo-China and Sumatra, the dictum that aluminium hydrate is the main product of tropical weathering instead of hydrated silicate will not hold, and doubts are entertained whether climate is the chief reason for the production of the former.

In fascicule 6, p. 14, vol. xviii of the *Bulletin du Service Géologique de L'Indochine*, the Director, Mons. F. Blondel, says when discussing the alteration of rocks in Indo-China, that in spite of the distinctly tropical character of the climate, the manner of weathering of the rocks is far from being entirely lateritic, by which he means the formation of aluminium hydrate. The granites decompose as in Europe to an "*arène sableuse*", and if the rhyolites, basalts, and eruptive rocks generally afford lateritic types of weathering with concentration of aluminium and iron, the process is never complete, but some clay is always present. In fascicule 3, p. 8, of the same *Bulletin*, Mons. Blondel comments on this as follows :—

"On est conduit à se demander, en conséquence, si le schéma classique qui divise les altérations des roches en altérations des pays tempérés et en altérations des pays tropicaux, correspond bien à la realité et si le climat est bien la cause profonde de la difference reconnue entre les deux types extrêmes d'altérations."

Mr. A. C. de Jongh, the Director of the Netherlands Indies Geological Survey, permits me to quote the following passage from an advance copy he has let me see of a paper on soils in the East Indies :—

"In this connection I want to mention an hypothesis, at one time suggested to me by Mohr, and that was lately affirmed, I think, by V. M. Goldschmidt (cf. *Handbuch der Bodenlehre*, Band iii, note on p. 254), that the presence of free $Al(OH)_3$ in a product of rock weathering is controlled not so much by the tropical climate, but rather by the mineralogical composition of the parent rock. There are, indeed, a number of observations, also from the Dutch East Indies, which seem to indicate that the weathering of orthosilicates (anorthite, nephelite), perhaps also of some metasilicates (leucite, pyroxene, amphiboles) often gives rise to allophane clays ($Al_2O_3.SiO_2$ aq.) and Al-hydroxydes (' Allite ' in the sense of Harassowitz), but that kaolin clays ($Al_2O_3.2SiO_2$ aq. ' siallite ') are the normal product, inside and outside the tropical zone, of the weathering of the more acid silicates, especially of the polysilicates albite and orthoclase.

"The predominance in Europe of acid igneous rocks (granite) that mainly consist of polysilicates, and the very common occurrence of basic igneous rocks in the tropics, perhaps have led to wrongly including the presence of Al-hydroxyde in the definition of ' tropical ' weathering."

In Malaya there is no doubt that the main product of weathering in acid igneous rocks is an hydrated silicate of aluminium. If it is not kaolin it is something so closely akin to kaolin as to be hardly distinguishable. I say this because the late Sir John Harrison, who kindly analysed some kaolinized orthoclase crystals for me, suggested that the silicate might be halloysite. Neither I nor anyone else has had reason to think that halloysite is the general weathering product. On the other hand, over basic rocks, such as the dolerite of Kuantan, aluminium hydrate is a general weathering product.

So far my contributions to the literature on laterite have been destructive criticism, as I would drop the word altogether unless used as Buchanan originally used it. I think I have good reason for this attitude because the originator of the term has been ignored by most geologists. One author went so far as to say that the "setting" property of laterite is not an essential characteristic, but that property is the chief reason, one might say the only reason, why the name exists. No analysis of Buchanan's type-rock has been made, though he described it 123 years ago, and in spite of the long discussion that began in 1909. A letter from the office of the Director of the Geological Survey of India, dated 23rd January, 1930, informs me that Buchanan's laterite is a detrital form varying from "limonitic hematite to argillaceous or siliceous limonite".

As Buchanan stated that his laterite was above granite I suspect that it is chemically as well as physically like some of our Malacca laterite and that hydrated silicate of aluminium is the general weathering product of granite in India as well as in Malaya, Indo-China, and the Netherlands Indies. To what an extent Buchanan's term is being misused has been brought home to me forcibly by finding that pedologists regard as a "lateritic" soil a soil in which hydrates of aluminium and iron are concentrated in the A or upper horizon of the soil, whereas a "podsol" is a soil in which the hydrates are concentrated in the B and C or lower horizons.

It will certainly be impossible for me to do enough work now in other countries to prove my ideas, but I put forward this constructive suggestion: wherever rocks weather an hydrated silicate is the main product of the felspars in acid igneous rocks, but in basic rocks varying amounts of aluminium hydrate are formed. Sometimes in acid igneous rocks the hydrated silicate undergoes further decomposition to a hydrate, the cause not being yet determined, and bauxite is formed. Such rich concentrations of aluminium hydrate are commoner in basic rocks. So-called "tropical weathering" is only an intensification of weathering in temperate climes due to greater heat and greater moisture.

J. B. SCRIVENOR.

EDITORIAL NOTE.

In the hope of saving much correspondence, the Editor ventures to remind contributors that all plates and figures *must* have titles. This is essential for indexing purposes.